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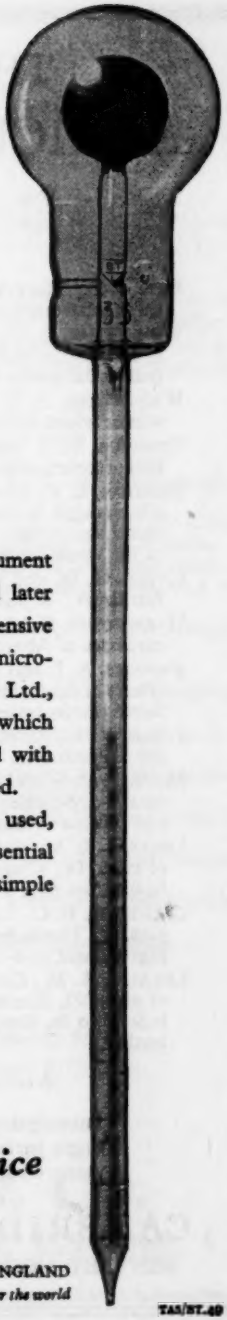

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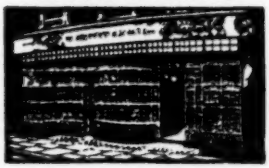

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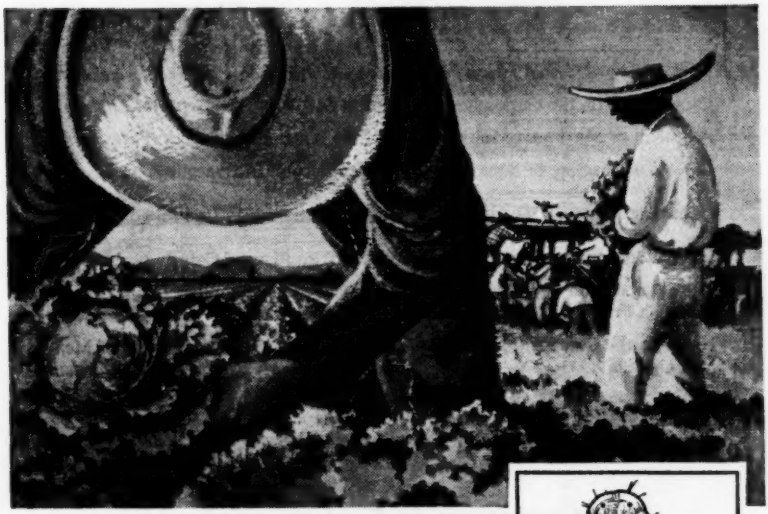

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AN EXPLORATORY ANALYSIS OF A LARGE SET OF 3×3×3 FERTILIZER TRIALS IN INDIA

F. YATES AND S. LIPTON
(*Rothamsted Experimental Station, Harpenden*)
and
P. SINHA AND K. P. DAS GUPTA
(*Department of Agriculture, State of Bihar, India*)

Summary

The Rothamsted electronic computer was used to make a combined analysis of 238 single-replicate 3×3×3 trials on rice, carried out in the State of Bihar, India, in the 1956/7 crop season. The three blocks of each replicate were on three separate fields in a village; it is shown that this had little effect on the estimates of the interactions or experimental error. The experiments attained satisfactory accuracy and showed good responses to N and P, and smaller responses to K, with little interaction between the factors. There were considerable variations in response from thana to thana. The responses showed little correlation with the soil classification (clay, loam, or sandy).

IN 1956 the State of Bihar in India began an extensive series of 3×3×3 factorial fertilizer trials on cultivators' fields. In each crop season something of the order of 500 experiments (single replicates) on various crops were carried out. A full analysis of the results of such an extensive series of factorial trials presents considerable computational problems, and it was therefore considered that it would be worth while to see whether such analyses can be satisfactorily handled on an electronic computer. As an initial test the results of 238 experiments on paddy in the season 1956/7 were analysed on the Rothamsted computer. The present paper gives an outline of the methods of analysis and the results so far obtained.

The handling of data from trials of this kind is becoming of increasing importance, since surveys of fertilizer responses by the use of factorial trials on cultivators' fields are being increasingly undertaken in underdeveloped areas. The present Bihar series of experiments, based on the 3×3×3 design planned by Dr. P. Sinha, is a continuation of the earlier series of non-factorial trials of various types begun in 1948 on the initiative of Dr. H. N. Mukerjee. The use of the 3×3×3 design marks a bold innovation in trials of this type, which, as will be seen from the results of this paper, has been abundantly justified by the increased accuracy of the results and the wider scope of the information provided.

Details of the Bihar experiments

The experiments were carried out on randomly selected cultivators' fields in randomly selected villages throughout the State. Owing to the generally small size of cultivators' fields it was impossible to have a complete replicate (27 plots) on a single field, and therefore the three blocks

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of a replicate (with 2 d.f. from the 3-factor interaction confounded) were located on three different fields within a village. This introduces certain complications which are discussed below.

Plots of standard size (1/20 acre) were used throughout, and in the tables of this paper all yields and responses have been converted to maunds per acre (1 maund = 82·28 lb.). An additional control plot ($N_0P_0K_0$) was included in each block, so that each block contained ten plots. For each block of an experiment the soil type, clay, loam, or sandy, was recorded and also whether the plots were irrigated or not. The confounding was of the balanced type, the replicates being divided into groups of four, with a different pair of degrees of freedom from *NPK* confounded in each member of a group.

When planning the experiments the State was divided into eight zones, corresponding to the main soil types. The fertilizer levels were different for the different zones. Those adopted for the experiments on paddy are shown in Table 7 below (p. 272). These variations in level do not appear to have had any advantage, since the zones which were assigned higher dressings did not in fact show higher responses per unit dressing. They have the disadvantage of making comparisons between the responses of the different zones somewhat more difficult.

The different zones have been kept separate in the analyses, as were irrigated and unirrigated experiments. The numbers of experiments (single replicates) in the different zones included in the analyses of variance by districts, &c., and those excluded for various reasons, are shown in Table 1.

TABLE 1. *Numbers of Experiments (Single Replicates)*

Zone		*A*	*B*	*C*	*D*	*F*	*G*	*H*
Included in A. of V. by districts, &c.	Irrigated	26	16	8	..	..	..	..
	Unirrigated	13	12	59	44	..	..	17
Incomplete		4	1	4	3	..	..	1
Split between irrigated and unirrigated		5	..	1	7	1	2	..
Numbers inadequate for analysis		..	..	..	3	3	8	..

The mean yields of the experiments are shown in Table 2, and the percentage standard errors per plot (calculated as explained below) in Table 3. In general these standard errors may be regarded as very satisfactory for this type of experiment. Zone C exhibits a rather high degree of variability, probably due to the location of paddy fields in the depressed pockets on hill bottoms where the fertility gradient generally varies from field to field on account of uneven and irregular deposits of hill washings. Hence it seems that the variability is naturally a characteristic of this zone itself and not merely a consequence of a few very inaccurate experiments.

A minor defect of the experiments is that the same randomization was adopted for all the replicates within a zone with the same type of confounding. This simplified the preparation of forms and the conduct of the field work, but is not advisable for statistical reasons. It is not considered, however, that it is likely in this case to have caused any

serious disturbance in the results, since within a zone there were four different random patterns for the four types of confounding.

TABLE 2. *Mean yields (maunds per acre) of Experiments included in the Analyses of Variance by Districts, &c.*

Zone	*A*	*B*	*C*	*D*	*H*
Irrigated	25·7	25·1	28·6	..	..
Unirrigated	20·7	25·5	31·7	23·7	22·8

TABLE 3. *Standard Errors per Plot (per cent. of mean yields)*

Zone	*A*	*B*	*C*	*D*	*H*
Irrigated	9·0	13·3	17·3	..	..
Unirrigated	12·2	6·7	16·6	13·9	12·1

Procedure of Analysis on the Computer

It would take too much space here to discuss in detail the problems that arose in the conduct of the analysis on the electronic computer and their methods of solution, but the following points may be mentioned.

The analysis was conducted in two parts. In the first part each individual replicate was analysed in the manner described in the next section. The results of the analyses were temporarily stored on various available tracks on the magnetic disk and were punched on to paper tape whenever the tracks became full. Since a great amount of material required to be punched at this stage the operation was time-consuming, both in the punching and in the subsequent re-reading into the machine for the second part of the analysis. This consisted of separate analyses of variance of each main effect and interaction for each zone, irrigated and unirrigated separately, by districts, &c. and similar analyses by soil type. The amount of reading-in was substantially increased by the fact that in the analyses of variance by districts, &c., each effect and interaction was analysed in a separate operation so as to avoid programming complications, and this necessitated the whole of the intermediate tapes being read-in for each separate analysis. For the analysis of variance by soil type this was avoided by running all the analyses simultaneously (with some necessary additional programming complications).

It was at first thought that the standard programme (already available) for the analysis of a $3 \times 3 \times 3$ single replicate would be suitable for the first part of the analysis. However, on examination it was found that considerable modifications would be required, and as in addition a new machine modification had recently been introduced which enabled much more rapid calculation of the necessary sub-totals, it was decided to write a new programme specially designed for the requirements of the Bihar analysis. This and the programming of the second part of the analysis took considerably longer than had been estimated, partly

because of the minor complications in the design and the various different types of result that it was considered advisable to make available and partly because of the novelty of the problem.

The new modification to the machine enabled the analysis of single replicates to be carried out with very great speed. The actual computations for a replicate took only 5 seconds, compared with about 1 minute for the standard $3\times3\times3$ programme (which, however, performs somewhat different operations). The overall gain of time was of course proportionately much less. Reading-in the plot yields of a replicate took 5 seconds and the punching out of the intermediate results considerably longer. (The treatment combinations for the different plots, being in a fixed order within a zone for a given type of confounding, only had to be read-in once at the beginning of a zone analysis.) The waste of time in the punching out of the intermediate results and subsequent re-reading into the machine would, of course, have been largely avoided had magnetic tape been available.

Throughout the computations very full use was made of total checks and it is not considered likely that there are any serious errors in the final results, though it cannot be claimed that all of the figures have been individually checked.

Since the analysis was of an exploratory type a considerable volume of results of various kinds was printed out. In future analyses some of these results might be dispensed with. On the other hand, in work of this kind it is useful, for example, to have the results of every replicate separately (in the style of Table 4 below) since although the majority of these will never require to be examined in detail they can, if available, be glanced through for anomalous results and are also useful for reference if any suspicious features emerge at later stages of the analysis. The alternative of only printing out results that appear anomalous on certain tests performed by the machine does, of course, save a large amount of tabular matter and machine time, but introduces programming complications which are not worth while in work of this kind and has the disadvantage that the results of all individual experiments are not available for subsequent reference. Moreover, it is usually difficult to decide what anomalies are worth testing for.

Analysis of the Individual Experiments

In the analysis of the individual experiments the standard procedure for the analysis of single-replicate $3\times3\times3$ experiments was followed, with the following modifications.

Partitioning of Main Effects

The customary partitioning of the 2 d.f. for main effects is into orthogonal, linear, and quadratic components, e.g. for N into

$$\begin{aligned} N_L &= \bar{N}_2-\bar{N}_0 \\ N_Q &= \bar{N}_2-2\bar{N}_1+\bar{N}_0, \end{aligned} \qquad \text{(A)}$$

where $\overline{N}_0$ is the mean of all plots receiving N_0, &c. In the present analysis these were replaced by the orthogonal components

$$N' = \tfrac{1}{2}(\overline{N}_2+\overline{N}_1)-\overline{N}_0$$
$$N'' = \overline{N}_2-\overline{N}_1. \qquad \text{(B)}$$

The first component, N', of this pair may be termed the *general response* to N and is the average of the responses to the single and double dressing. The second, N'', may be termed the *additional* response to N and is the additional response to the double dressing over that to the single dressing.

In forming the estimate of error from two- and three-factor interactions the components $N'P'$, $N'K'$, $P'K'$ were removed from the two-factor interactions, leaving 15 d.f. for error.

There is no need here to enter into a detailed discussion of the relative merits of the conventional linear and quadratic partition A and the partition B used here, but the following points may be noted.

Partitions A and B may be looked on as the extremes of a family of partitions of which the first component is a weighted mean of the responses to the single and double dressings. If the response were known to be linear then the first component of A would give the most accurate estimate of the response, whereas if it were known that there was no additional response to the double dressing the first component of B would do this. In intermediate cases an intermediate weighting would give the most accurate single estimate for the purpose of comparing the responses in different experiments, but the use of intermediate weights is rarely worth while in practice.

With the curvatures normally encountered in fertilizer response curves there is usually little to choose between partitions A and B on the score of efficiency and the choice largely becomes one of convenience of interpretation. It should be recognized that whichever the form adopted for analysis the two components jointly contain the whole of the information on the main effects. The only difference in the analysis of variance is the components of interaction that are removed from the estimate of error.

Evaluation of Main Effects for Individual Blocks

In addition to evaluating the main effects N', N'', P', P'', K', K'' for each complete replicate, these main effects were also evaluated for each block separately.

This was done for two reasons. First, provided the interactions are small it enables information from replicates in which the soil type and use of irrigation differ from block to block to be incorporated without difficulty in the classifications required in the second stage of the analysis; and second, it enables the variability in responses from block to block of a replicate to be studied. The reason why this is of interest is explained in the next section.

Treatment of Additional Controls

The additional control ($N_0P_0K_0$) plots in each block were dealt with as follows.

In the blocks in which there were two $N_0P_0K_0$ plots these were meaned for the main analysis (the resultant increase in precision being ignored) and in addition the squares of their differences were summed so as to give an additional estimate of error. This estimate was kept separate from the main estimate of error, since if the errors at the different yield levels are not homogeneous, combination of the two estimates would not give the error appropriate to the main comparisons.

In the blocks with only one control plot the difference of the control plot from the remainder of the block was computed and meaned by each type of block separately, in order that comparisons could be made, if so desired, with the expected values estimated from the main effects and interactions.

Multiway Tables

In addition to the main effects and interactions, totals of the separate treatment combinations were punched, so that any required multiway tables for the irrigated or unirrigated experiments of a zone could be constructed.

Presentation of the Results of the Individual Experiments

In order to enable the results of any particular experiment to be examined if required, the results of each experiment were printed out in the form shown in Table 4. This was done for all the 238 experiments. In experiments which contained both irrigated and non-irrigated blocks or in which a block was missing no estimate of error was calculated.

TABLE 4. *Example of the Tabulation of the Results of the Three Blocks of a Village* (*maunds per acre*)

Mean Yield 24·2

Block	N'	N''	P'	P''	K'	K''	*S.E. of* N', P', K' (*means*)	*S.E. of* N'', P'', K'' (*means*)
1	7·3	5·0	5·1	3·5	2·8	0·0	..	..
2	7·7	4·7	9·4	4·5	4·2	2·3	..	..
3	5·8	1·3	7·6	6·5	7·3	−1·0	..	..
Mean	6·9	3·7	7·4	4·8	4·8	0·4	1·25	1·44

Complications arising from the Placing of Blocks on Different Fields

In a confounded experiment a variation in response to a factor from block to block of a replicate will emerge in the analysis as an interaction between other factors. This fact is well known, and from time to time has been used as an argument against confounded designs. It has been shown, however, that in experiments arranged in the customary

manner with all the blocks of a replicate grouped together on a field, variations in response from block to block are not usually of sufficient magnitude to cause any complications of this nature [1, 2].

In the Bihar experiments, in which the blocks of a single replicate were on separate fields, there is likely to be greater variation in responses from block to block, and it was therefore considered worth while, as mentioned above, to arrange the analysis so that this point could be examined.

Each block of a replicate is in effect a fractional ($\frac{1}{9}$) replicate of a $3\times3\times3$ design. The ordinary theory of fractional replication, or tabulation of the actual treatment combinations in the different blocks, shows that for a single block the 2 d.f. for N have as aliases 2 d.f. for PK and 2 d.f. for NPK. Taking the replicate as a whole, therefore, the 4 d.f. for $N\times$blocks is equivalent to 2 d.f. for PK and 2 d.f. for NPK, and similarly for $P\times$blocks and $K\times$blocks.

The actual aliases and equivalences depend on which pair of d.f. for NPK are confounded. In the notation of *Technical Communication No. 35* [3], if, for example, $NPK(W)$ is confounded, we have the equivalences:

$$N\times\text{blocks} \equiv PK(\mathcal{J})+NPK(Z)$$
$$P\times\text{blocks} \equiv NK(I)+NPK(Y)$$
$$K\times\text{blocks} \equiv NP(I)+NPK(X)$$

Adding in $PK(I)$ to the first of these equivalences, splitting up $N\times$ blocks, and separating out $P'K'$ (which is straddled across $PK(I)$ and $PK(\mathcal{J})$) we have

	d.f.	*Expectation*		*d.f.*	*Expectation*
$N'\times$blocks	2	$A+\frac{1}{8}C+E$	$P'K'$	1	$\frac{1}{4}(A+B)+C+E$
$N''\times$blocks	2	$B+\frac{1}{8}C+E$	Error	5	$\frac{7}{20}(A+B)+E$
$PK(I)$	2	$\frac{1}{4}C+E$			

and similarly for the other two equivalences.

In the absence of any differential response to N in the different blocks and of any PK interaction, all the mean squares will have an expectation equal to the error mean square E. If there are differential responses represented by an additional mean square A to $N'\times$blocks and B to $N''\times$blocks, and a PK interaction confined to $P'K'$ and represented by an additional mean square C to $P'K'$ the expectations of the mean squares will be found to be those shown above.

Thus the existence of differential responses to N inflates the mean squares for both $P'K'$ and certain components of error, and the existence of a $P'K'$ interaction inflates the mean square for $N\times$blocks. The actual amount of cross-inflation, however, is relatively small for $3\times3\times3$ experiments, as is shown by the above expectations. Moreover, in a set of experiments there is no danger of misinterpretation, since differential responses to N will merely increase the apparent variability of $P'K'$ from experiment to experiment, whereas any real $P'K'$ interaction will,

in so far as it is constant, be shown up by the consistency of the estimates of $P'K'$ from experiment to experiment. These differences can be clearly exhibited by the form of analysis of variance set out below.

Analysis of Variance of the Combined Results by Districts, &c.

Using the values of the effects and interactions determined in the analysis of the separate experiments, an analysis of variance by districts, &c., was carried out on each effect for the irrigated and non-irrigated experiments of each zone. Experiments which contained both irrigated and unirrigated blocks and those with a block missing were omitted entirely, since it was desired at this stage that the pooled error mean squares should be strictly comparable with the other terms in the analysis of variance.

For the main effects, N', N'', &c., the analysis of variance table is as follows:

Between blocks, within villages
Between villages, within thanas
Between thanas, within districts
Between districts
Mean response

For the interactions the first line is omitted, since the interactions are only estimated for whole replicates.

All analyses were tabulated in units of a single plot so that the mean squares of the analyses of the different effects could be compared with the pooled error mean square from the analyses of the separate experiments and with one another.

It should be noted that in analyses of variance of this kind, where the numbers of degrees of freedom of the variance components are all fairly large, strict application of the Z-test is liable to give misleading results owing to non-normality of the data. Not only are the errors of a given experiment not necessarily normally distributed but the experimental error is also likely to vary considerably between experiment and experiment.

As an example the results for Zone D, unirrigated, are shown in Table 5. The main features of this table are immediately apparent. There is a large general response to N with a substantial response to the second dressing, similar but smaller responses to P and a relatively small general response to K with no additional response to the second dressing. The interactions are all small and not significant when tested against the pooled experimental error.

Examination of the increase in variation with increasing size of subdivision shows that apart from N'' there is no evidence of variation in responses between villages within thanas. Apart from K'', there is clear evidence of variation between thanas.

N' and N'' show some evidence of differential responses between blocks within villages. This may account for the slightly high values of

some of the mean squares for $P'K'$. It is not, however, sufficient to inflate the error mean square substantially.

TABLE 5. *Analyses of Variance of Effects and Interactions by Districts, &c., for Zone D, Unirrigated (units of a single plot in maunds per acre)*

	d.f.	N'	N''	P'	P''	K'	K''	$N'P'$	$N'K'$	$P'K'$
Error	660	..	..	10·8		..	..	..	..	..
Blocks	88	15·1	14·9	8·7	9·7	11·6	10·8	..	..	..
Villages	20	11·9	23·9	7·4	4·1	8·4	10·1	4·4	1·6	5·0
Thanas	20	124·9	46·1	80·8	20·1	37·2	14·0	12·6	7·8	20·6
Districts	3	84·5	66·9	194·1	19·2	15·6	5·9	32·9	11·8	14·2
Mean	1	10,654·9	2,620·0	4,415·5	643·7	867·9	3·3	0·0	29·9	19·4

The mean squares are between the class shown and within the next class.

This last point can be further examined by extracting those components of NP, NK, and PK (2 d.f. each) which are independent of the differential responses between blocks within villages. This can be done from the figures of Table 5 by adding together the sum of squares corresponding to the error mean square (660 d.f.) and all the sums of squares for $N'P'$, $N'K'$, and $P'K'$ (132 d.f. in all), and then subtracting the sums of squares for N', N'', P', P'', K', K'' between blocks within villages (528 d.f. in all). This gives a mean square of 8·2 (264 d.f.), which is not much less than the pooled error mean square, 10·8. This mean square will, of course, be inflated by any real interaction components, but these are clearly trivial in this zone.

The tables for the other zones (not reproduced here) show similar features, with little evidence of any appreciable block-to-block variation within villages, but with some variation between villages within thanas in a few cases.

In some of the zones there is some evidence of the existence of interactions, but these are all relatively small. The estimates are shown in Table 6. This table shows that in irrigated experiments there is a tendency to negative $N'P'$ interactions with variable manifestation and also to a negative $N'K'$ interaction. Negative $N'P'$ interactions also occur in some unirrigated experiments in Zone B. Otherwise in the unirrigated experiments there is a general tendency to small positive interactions.

The mean responses for the different zones are shown in Table 7, together with the levels of the single dressings. In examining this table it should be borne in mind that (*a*) the levels of the dressings are not the same in all zones, (*b*) that the standard errors shown are those attributable to experimental error only and do not include village-to-village and thana-to-thana variation, and (*c*) that if the response to the double dressing were double that to the single dressing the additional response N'', P'' or K'', would be two-thirds the general response N', P', or K'. Good responses to nitrogen are shown in all zones, that for Zone C being exceptionally high; there is a tendency for slightly smaller responses in the unirrigated experiments. The responses to P are more variable, Zone C being again highest and Zone A the lowest. The

general responses to potash are relatively small but fairly consistent from zone to zone, Zone A being the lowest; there is no appreciable response to the double dressing of potash.

TABLE 6. *Estimates of Interactions (maunds per acre)*

	N'P'		*N'K'*		*P'K'*		*S.E.s*	
Zone	*Irr.*	*Not*	*Irr.*	*Not*	*Irr.*	*Not*	*Irr.*	*Not*
A	−0·4*†	−0·0	−0·5*	+0·1	−0·3	+0·3	±0·20	±0·30
B	+0·3	−0·3†	−0·2	+0·5*	+0·3	+0·8*	±0·36	±0·21
C	−0·7	+0·1	+0·3	+0·0	−1·1	+0·5	±0·76	±0·30
D	..	0·0	..	+0·4	..	+0·3	..	±0·21
H	..	+0·8*	..	+0·6	..	+0·2	..	±0·29

* Significant. † Significant variation.

TABLE 7. *Mean Responses (maunds per acre)*

		Nitrogen					*Phosphorus*			
		N'		*N''*			*P'*		*P''*	
Zone	*Dr.**	*Irr.*	*Not*	*Irr.*	*Not*	*Dr.**	*Irr.*	*Not*	*Irr.*	*Not*
A	25	6·2	5·6	2·2	2·9	30	2·8	3·5	0·9	0·4
B	25	6·4	5·4	3·1	2·1	30	4·7	5·2	1·5	1·5
C	20	9·6	8·1	5·3	3·9	25	6·6	6·5	2·6	1·8
D	30	..	6·3	..	3·6	30	..	4·1	..	1·8
H	20	..	5·6	..	2·7	20	..	4·0	..	1·5

		Potassium				*Standard errors†*			
		K'		*K''*		*N', P', K'*		*N'', P'', K''*	
Zone	*Dr.**	*Irr.*	*Not*	*Irr.*	*Not*	*Irr.*	*Not*	*Irr.*	*Not*
A	25	1·4	0·6	−0·0	−0·4	±0·19	±0·29	±0·22	±0·33
B	20	1·6	1·2	0·6	0·6	±0·34	±0·20	±0·39	±0·23
C	20	2·2	1·9	−0·8	0·3	±0·72	±0·28	±0·83	±0·32
D	20	..	1·8	..	0·1	..	±0·20	..	±0·23
H	20	..	2·6	..	0·3	..	±0·27	..	±0·32

* Single dressings in lb. N, P_2O_5, K_2O per acre.
† Based on pooled estimates of error within experiments.

This table does not, of course, give a complete picture of the variations in response, since, as pointed out above, there are substantial variations between thanas and between districts. In the course of the analyses of variance of the main effects and interactions the thana and district means were printed, together with the number of blocks contributing to each mean. Table 8 for the general response *N'* to nitrogen in Zone D (unirrigated), gives an example of such a table. The corresponding analysis of variance has already been given in Table 5. The large variations in response from thana to thana, already brought out by the analysis of variance, are very apparent in this table.

TABLE 8. *General Responses to N in the Thanas of Zone D, Unirrigated, Set out by Districts (maunds per acre)*

Muzaffarpur		*Saran*		*Champaran*		*Darbhanga*	
Blocks	*N'*	*Blocks*	*N'*	*Blocks*	*N'*	*Blocks*	*N'*
6	9·0	3	1·8	6	4·0	6	3·8
6	9·0	6	3·7	3	6·3	6	9·0
6	1·9	12	4·5	3	7·4	6	10·4
3	12·8	6	4·7	6	8·6	6	3·6
21	7·5	6	3·4	6	2·5	6	9·6
		6	2·7	6	2·5	30	7·3
		3	11·9	6	11·2		
		3	10·9	30	6·6		
		6	8·1				
		51	5·2				

As already mentioned only the results of complete experiments, the blocks of which were all either irrigated or unirrigated, were included in the analyses of variance, and therefore in the tables of thana and district means such as Table 8. Similar tables which include the incomplete experiments and those in which only some of the blocks were irrigated could easily be provided, but reference to Table 1 shows that the additional amount of data included would not be large. These tables were therefore not computed. In this connexion it should be noted that if there were evidence of substantial interactions the inclusion of incomplete experiments could only be made if some adjustments for interactions were made, and then only if the interactions were reasonably constant from experiment to experiment, since the interactions affect the apparent responses in the different blocks. In this case the computation would be much more complicated.

Soil Types

An analysis of variance according to the soil classification, clay, loam, or sandy, was also made, ignoring the thana and district classification. The results were, however, not consistent. The results for N', P', K' for Zone B are shown in Table 9. The differences in the P' responses are reasonably consistent for irrigated and unirrigated experiments but for N' they are not so consistent and for K' there is no agreement between irrigated and unirrigated experiments. Apart from Zone B the only significant association of response with soil type when the term 'between soil types' was tested against 'within soil types' was for N' in Zone A irrigated. It may be concluded, therefore, that this crude soil-type classification is not likely to be of much general value in assessing fertilizer requirements.

A more detailed examination of variations between soil types within thanas could, of course, be made, but as particular soil types tend to be associated with given thanas the data will be very non-orthogonal, and

the analysis would in any case be troublesome and scarcely worth while for the results of a single year. It has therefore not been attempted.

TABLE 9. *Responses on different Soil Types, Zone B (maunds per acre)*

Soil	No. of blocks		N'		P'		K'	
	Irr.	*Not*	*Irr.*	*Not*	*Irr.*	*Not*	*Irr.*	*Not*
Clay . .	18	20	4·3	6·3	3·5	5·4	0·8	1·9
Loam . .	22	9	7·6	1·5	4·5	2·2	1·2	0·1
Sandy . .	8	7	7·8	8·0	7·6	8·4	4·5	0·5
Level of significance .	..	..	1%	1%	5%	1%	1%	5%

Analyses Required for Further Batches of Data

The analyses described in this paper produced a large amount of numerical results, and it is worth considering whether such detailed analyses are required on future batches of data. From the present results it is clear that the differential responses in the different blocks are unlikely to be sufficiently large to affect the estimates of the interactions seriously, and that the thana is the smallest geographical unit that is likely to be of importance. If, therefore, future analyses were to be carried out on desk machines there would be no point in computing the main effects for each block separately. In addition the analyses of variance of the separate experiments might be omitted, only the main effects and interactions being computed. Tables, such as Table 8, of the thana and district means could then be computed, together with analyses of variance of the type of Table 5 (but omitting experimental error and the within-village components) in cases in which inspection of the tables of means indicated that such analyses might be of interest. The thana means could indeed be computed for each thana from the means of the separate treatment combinations of all experiments in that thana, but this would prevent any study of the consistency of the results from village to village.

If, however, the Rothamsted electronic computer is used there is little to be gained by modification of the present analyses, since the necessary programmes are already available and any change would require programme modifications. It is probably unnecessary to print the values of the main effects of the separate blocks of complete experiments, and possibly their computation might be suppressed. The decision on this point really turns on whether it is judged necessary to utilize the results of experiments which are incomplete or partially irrigated. Certainly with electronic computation the standard errors of the individual experiments should be computed and printed, since inspection of these errors provides a good control on the conduct and accuracy of the individual experiments and gross errors of recording or transcription. Thus in one experiment of the present set the yields of

two plots were missing and owing to a misunderstanding these were punched as zero. This was detected on inspection of the errors.

The main new work that is required is (*a*) an attempt to find explanations for the large thana-to-thana variations in the responses, and (*b*) a study of the year-to-year variations in response. The latter can only be tackled when the results of three years or so are available, unless the data from the previous series of non-factorial experiments are utilized. The former could be begun immediately, but can be better undertaken when the consistency of the differences from year to year has been examined. It might, however, be worth plotting the present results for N', P', and K' on a map and studying their distribution in the light of local knowledge.

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THE NGUNI BREED OF CATTLE. I. A DESCRIPTIVE REVIEW

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WITH PLATES 8 AND 9

The Origin of the Nguni [1, 2, 3, 4, 5, 6, 7, 8]

ALTHOUGH the early history of the ancestors of the modern Nguni and the respective migratory routes are unknown, several writers have advanced certain hypotheses. The Bantu tribes who were responsible for bringing the Nguni to south-eastern Africa, have been referred to as 'a people without a written past'. The Nguni is considered to be of Sanga type and the word 'Sanga' will be used in reference to the forebears of the Nguni breed and as a collective name to cover all breeds existing in Africa of similar blood lines descended from these forebears. The probable migration routes of African cattle are based on human migrations.

The modern breed name was adopted by the Committee of Investigation [6] (hereafter referred to as 'the Committee'), after consultation with Dr. Warmelo, Ethnologist of the South African Native Affairs Department, who suggested the name 'Nguni' [Bisschop, private communication]. The basic unit of the political system of the Bantu race was the 'clan'; several of these contiguous 'clans' formed a tribe, one of which was known as the Nguni, to which the Zulus and their offshoots, the Swazis, belonged. Hence such a name would be acceptable to both tribes.

Probable Migrations to Africa of the Parent Stocks of African Cattle

In view of the two beliefs that the Nguni (of Sanga type) is descended from either a cross between the Lateral-horned Zebu and the early Hamitic Longhorns, or a triple cross between the Lateral-horned Zebu, the Hamitic Longhorn, and the Brachyceros [J. P. Martinho and E. H. Castro-Amaro, personal communication] all three breeds will be traced here.

Lateral-horned Zebu. These cattle are thought to have lived originally in the coastal region of the Mongolian Sea, and to have acquired their Zebu characteristics only when that region became a desert. An early writer, Adametz, was of the opinion that these cattle were brought from north-western India by the Semites and eventually moved into south Arabia, whence they crossed into Somaliland. A slow dispersal of the invaders then ensued throughout Ethiopia and Upper Egypt.

Hamitic Longhorn cattle. These cattle are believed to have been descended directly from the giant-horned, wild, Nile Valley cattle which were later (in the Neolithic Age) the first to be domesticated in Africa.

Brachyceros cattle. These were reported to be descendants of *Bos nomadicus* and are Asiatic in origin. Early Asiatic tribes caused their movement westwards to Asia Minor and Europe during the Neolithic Age and, somewhat later, they moved into Lower Egypt.

[Empire Journ. of Exper. Agric., Vol. 27, No. 108, 1959.]

Mention is made of the Short-horned Zebu in the available literature but as this breed has no direct influence on the Nguni, it is omitted in this paper.

Intermixture of parent stocks and the evolution of new breeds. The first cattle invasion of Africa by the Brachyceros was a result of people of Mediterranean stock overrunning Lower Egypt where the Negroid tribes were situated. The Hamitic Longhorn was thus, over a period of several centuries, gradually displaced, causing its migration westwards with its negroid owners.

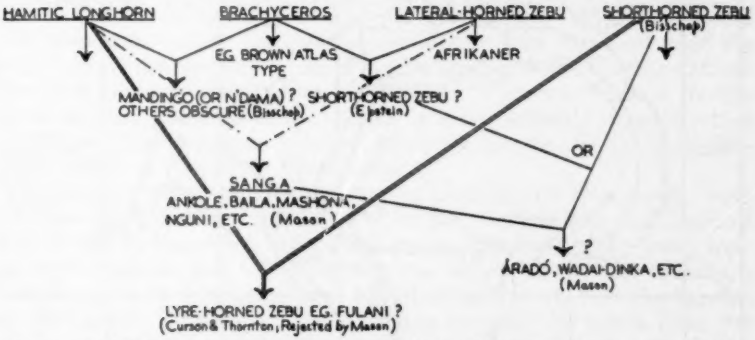


FIG. 1. Relationship of African breeds of cattle. (Extracted from Curson and Thornton [2], Bisschop [3], and Mason [5].)

The next important invasion occurred towards the end of the third pre-Christian millennium when Semitic tribes, accompanied by their Lateral-horned Zebus, crossed into the present Somaliland and spread into Ethiopia and Upper Egypt. The available literature, as to when the actual period of intermixture of the Hamitic Longhorns and the Lateral-horned Zebus occurred, is vague. However, since not all the Hamitic cattle would appear to have migrated westwards, intermingling of Hamitic and Lateral-horned Zebu blood resulted in the Sanga type, of which the Zulu and Swazi breeds are sub-types. This Semitic invasion naturally compelled the negroid tribes in Upper Egypt and Ethiopia to retreat southwards.

The belief that the Sanga breed is the outcome of a triple cross (Lateral-horned Zebu, Hamitic Longhorn, and Brachyceros cattle), as held by some investigators, is based on the shape of the skull, which is held to show signs of Brachyceros infusion.

Other crosses among these three parent stocks are:

Brachyceros × *Hamitic Longhorn.* The Mandingo cattle (or N'Dama) of Liberia may be this cross.

Lateral-horned Zebu × *Brachyceros.* Apart from Epstein's theory concerning the derivation of the Short-horned Zebu in Asia (i.e. *Bos indicus* × *Bos brachyceros*) these breeds never appear to have been in direct contact. Bisschop discredits Epstein's theory on the basis of conformational differences, especially of the hump, between the Lateral-horned and the Short-horned Zebus.

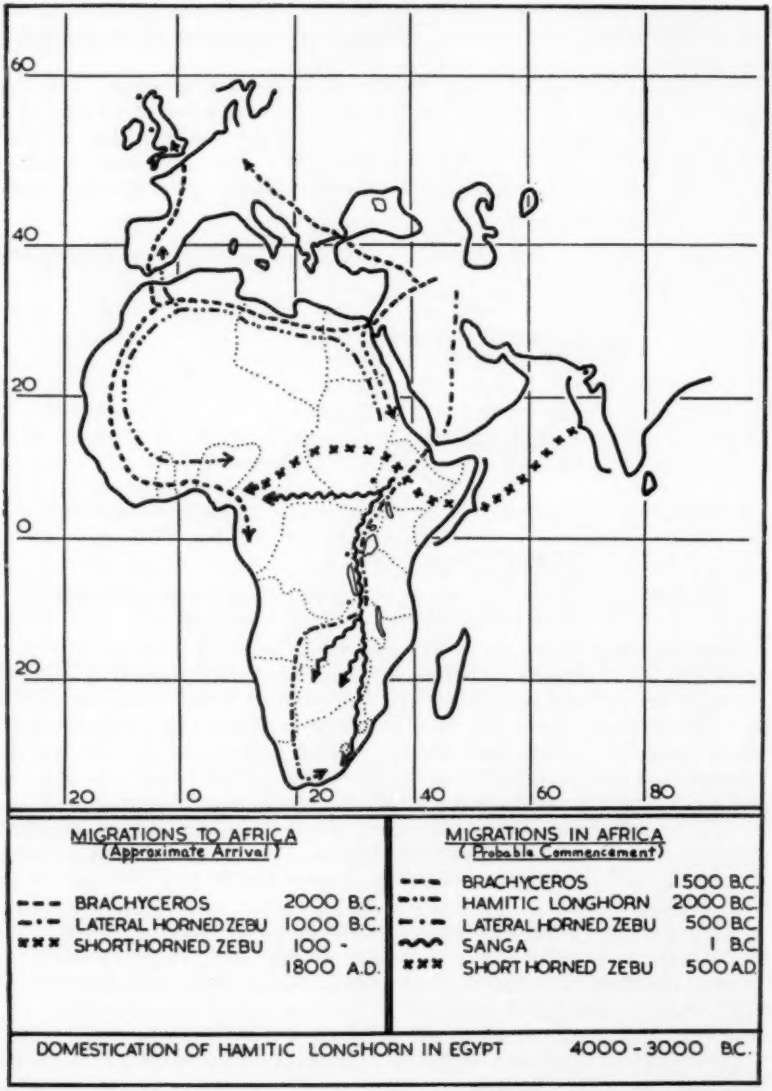


FIG. 2. Probable migration routes to, and in, Africa prior to 1652. (After Curson and Thornton [2].) With special reference to routes taken by negroid tribes and their cattle.

A diagrammatic representation of the relationship of the African parent stocks of cattle and their descendants is shown in Fig. 1 (compiled by the writer from the sources indicated).

Probable Migrations within Africa of Parent Stocks and their Descendants

Fig. 2 illustrates the popular version of the various routes believed to have been taken by the early tribes and their bovines. Again these routes are based on the accounts of human migrations. The figures illustrate the early migrations in Africa and explain visually how the numerous breeds and sub-breeds, descended from the original parent stocks, became established in various parts of the African continent.

The Hottentots, being in the vanguard of the human migration southwards, were able to keep their herds of Lateral-horned Zebus free from admixtures with other breeds. The reason why the Hottentots should be in possession of the Lateral-horned Zebus; and the Bantus of the Sanga type, is not apparent. As is shown by Fig. 2 the Bantus did not follow the same course as the Hottentots. The route taken by the Lateral-horned Zebu to South Africa is controversial; some workers believe that early Portuguese shipwrecks were responsible for the introduction of the Afrikaner to South Africa.

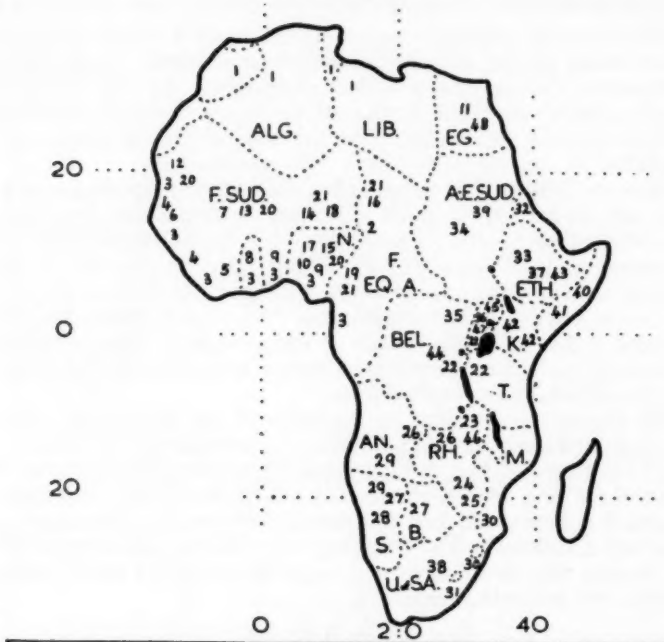
'Following comparatively close on the heels of the Hottentots, were the tribes which included the Bantu of today.' On reaching the Zambezi River, 'it can be imagined, the various tribes dispersed, some going west into Bechuanaland and Ovamboland, and others south into Southern Rhodesia and the Transvaal, and the remainder east, into Portuguese East Africa and Zululand'. The breaking away of the tribes from the main body during this slow migration, accounts for Sanga cattle being encountered in the following regions:

TABLE 1. *Sanga Types and their General Location in Africa*

Ankole	Southern Uganda; north-west Tanganyika and eastern Belgian Congo including Ruanda-Urundi.
Baila	Northern Rhodesia.
Mashona	Southern Rhodesia (Curson and Thornton's Makalanga).
Matabele	Southern Rhodesia.
Setswana	Bechuanaland and surroundings.
	(i) Barotse—Northern Rhodesia and eastern Angola.
	(ii) Batawana—north-west Bechuanaland.
	(iii) Damara—South-west Africa.
Ambo	South-west Africa and southern Angola.
Nguni	Zululand, Swaziland, and southern Mozambique.
Bolowana	Cape Province.

Fig. 3 (compiled by the writer from the sources mentioned) shows the general location of the indigenous cattle breeds of Africa, inclusive of the Sanga type. Sanga type cattle are also found in Madagascar and in West African territories, e.g. the Bornu.

With reference to Zulu cattle, Bryant [4] considers it probable that the advent of the European in South Africa caused the Zulu tribe to settle, with their cattle, on the east coast of Natal. Robinson [9] records that, as far back as 1689, certain shipwrecked mariners described Natal as being 'full of cattle'. He mentions that 'along the coast [of Natal] a hardy breed of small size known as the Zulu, is found to suit the country best'.



REFERENCE			
BRACHYCEROS	HUMPED (ZEBU)	25. MATABELE	LATERAL H. ZEBU
1. BR. ATLAS TYPE	12. MAURE	26. BAROTSE	38. AFRIKANER
LAKE CHAD	13. TUAREG	27. BATAWANA	E. A. SH. H. ZEBU
2. KURI & K × ZEBU	14. AZAOUAK	28. DAMARA	39. SUDANESE
SMALL HUMPLESS	15. SHUWA	29. AMBO	40. JIDDU
3. DWARF SH. HORN	16. FELLATA	30. N'GUNI	41. BORAN
4. N'DAMA	17. SOKOTO	31. BOLOWANA	42. NANDI
5. BAOULE	18. DIALI	? SANGA × SH. H. ZEBU	43. ABYSSINIAN
HUMPED × H'LESS	19. AD. FULANI	32. ARADO	44. LUGWARET
6. DJAKORE	20. FULANI	33. UOGHERA	45. BUKEDI
7. BAMBARA (Meré)	21. RED BORORO	34. SUD. LONGHORN	46. ANGONI
8. "SANGA"	SANGA (TRUE)	35. WADAI-DINKA	47. WEST NILE
9. BORGU	22. ANKOLE	36. NGANDA	ETC.
10. BIU	23. BAILA	37. GALLA	BUFFALO
11. EGYPTIAN	24. MASHONA		48. EGYPTIAN.

FIG. 3. Indigenous cattle breeds of Africa. Map showing their general distribution. (Extracted from Curson and Thornton [2], and Mason [5].)

The Relationship of the Nguni with other Indigenous Breeds [2, 3, 5, 10, 11, 12]

Three of the parent stocks of African cattle, namely: the Hamitic Longhorn which was non-humped; the Lateral-horned Zebu—with a well-developed hump; and the Brachyceros—non-humped, are apparently responsible for the outcome of the Nguni. Either two or three

of the above breeds interbred to produce the Sanga type as previously mentioned.

Judging from 'wall carvings and paintings, the Hamitic Longhorns appear to have been conformationally characterized by a relatively deep body, straight topline, without a hump but with a well-developed loin and straight rump'. The head was short and broad and broken colours apparently were the rule, the 'nkone' or 'sided' colour scheme being particularly common.

The Brachyceros was in those days very much smaller in all respects than the Hamitic Longhorn and tended somewhat towards the milk-type conformation. It was also hardy. Other features were, *inter alia*, a convex profile, oval horns (in cross-section), well-developed hump and dewlap, and a sloping rump. The conformational differences between these three basal types are adequately listed by Bisschop [3].

Within historic times a third cattle invasion of Africa ensued, as a result of which the Short-horned Zebu gained a firm position in eastern Africa. Numerous crosses with Sanga cattle by the Short-horned Zebu resulted in the formation of 'new breeds'. Otherwise, the relationship, as far as the Nguni is concerned, is a negative one.

Fig. 1 summarizes the relationship between the present-day breeds of African cattle developed from the parent stocks.

The Sanga group ('Sanga' × trek-ox) 'constitute the most important group of African cattle of cross-bred origin' and should not be confused with the West African 'Sanga' to which references are made by Curson and Thornton [2] and Stewart [12].

The Principal Location of the Nguni Breed

Nguni cattle are found wherever the descendants of original groups of the human Nguni tribe have settled. The shaded areas in Fig. 4 represent the present position of the breed [6]. The main area is bounded in the north by the Komati River in Northern Swaziland and extends southwards to the Tugela River in Natal, thereby including Zululand proper. The coast forms the eastern boundary and the Drakensburg virtually forms the western boundary in Swaziland, the line continuing south, passing east of Vryheid, through Babanango (BAB) to Mapumulo. However, typical Nguni cattle are found in the Mozambique Territory and in Pondoland, but to what extent, and to what localities they are confined, has still to be ascertained.

Ecology, Characteristics, and Usefulness of the Nguni

Adaptability of the Nguni to their Environment

The remark made by Robinson [9] about the Zulu being a 'hardy' breed best suited to the coastal region of Natal, serves to indicate its early reputation.

Curson [13] alludes to this point, saying 'chiefly as a result of adaptability to environment, the Zulu beast has not only established itself in Mozambique, Swaziland, and Zululand, but has acquired features which are of particular value to the European and Native alike'. Reference

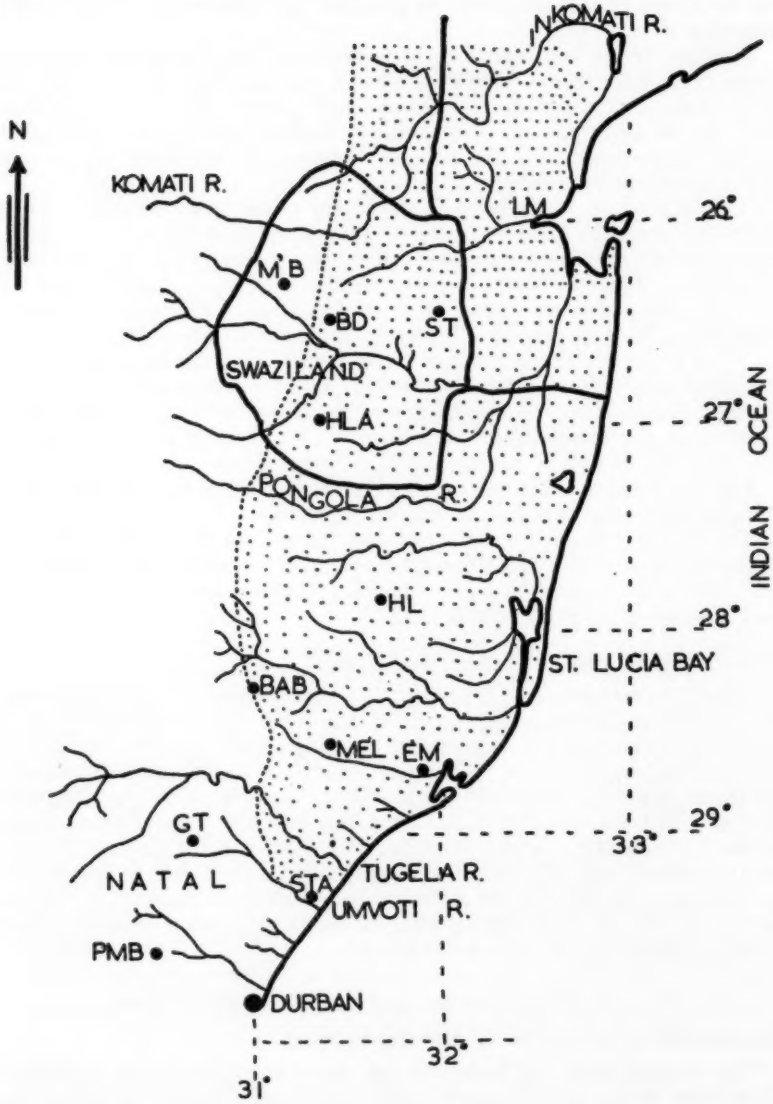


FIG. 4. Principal location of the Nguni breed. [6]

is also made to the stamina of the oxen and to the breed's resistance to tick-borne diseases.

Faulkner [14] states that of approximately 36,450 deaths of Zulu cattle in Swaziland in 1945, 'only 4 per cent. died from any recognised disease while the majority of 30,000 deaths must be attributed to starvation and old age', the peak mortality being during the months of September and October of that year.

The Committee [6] reported in 1948 on the success with which the Nguni breed has maintained itself in the coastal belt which is 'considered as some of the most trying and unhealthy cattle country in South Africa'. This success is attributed to the hereditary resistance to tick-borne diseases, and to other factors such as tough hide, the short glossy coat, and the pigmentation round the eyes.

There is no specific information available regarding the resistance of the Nguni to nagana, although many farmers in the tsetse-fly regions maintain that Nguni cattle do possess a degree of immunity. Henning [15] reports that 'apart from some breeds of West African cattle, which have a very high natural resistance, all breeds, whether imported or native, are more or less equally susceptible'.

Characteristics of the Nguni [2, 6, 10, 13, 14]. See Plates 8 and 9.

Conformation. The Nguni is small to medium in size (cows 450–1,000 lb. and bulls 700–1,300 lb.) depending on nutritional conditions. The skeletal bones are dense in nature, and the Ngunis are of a high general quality. Body conformation tends more towards the accepted milk type than to the beef type. Their depth is good, with moderate width and a satisfactory capacity. The mature cows have fairly short legs with good feet.

Compared with the Afrikaner, the ratio of surface area to body weight in the Nguni appears to be smaller, in view of the lesser development of the dewlap and umbilical fold. The dewlap is medium-sized, thin, and refined. The hump is hardly noticeable in the mature cow but is fairly well developed in the full-grown bull. The hump has been suggested as a means of classifying African cattle, according to its situation, structure, or function. Using the hump as a guide, Curson and Thornton have classified the Sanga as a sub-type of the pseudo-Zebu group.

The barrel of the Nguni is of good length and strength and the rump is inclined to droop towards the tail; the rear quarters are light.

The head is of good size and length with a flattish poll; it has a broad dished forehead being widest between the eyes, although the orbital processes are not prominent. The face is wide and straight to slightly convex in profile. In general, the Nguni is characterized by the quality and strength of its head. The muzzle is broad and the ears are refined-looking, being small with a sharp apex.

The horns are of two types, narrow or wide-spreading, and are of a high quality. A peculiar constriction is usually observed at their base, while the diameter is smallish, the horns tapering to fine tips. In cross-section the horns are usually round and are noticeably lyre-shaped in the mature cows.

Fine-type Nguni have soft, fine glossy coats. The udder and teats are small to moderate, while the milk veins are not prominent.

Colour. The Committee classified Nguni colours and colour patterns as follows:

Whole colours:

White coat	Lightly pigmented hide.
Black coat	Darkly pigmented hide.
Brown coat	Fairly dark pigmentation of the hide. Said to be associated with hardiness.
Red coat	Pigmentation darkish. Sometimes regarded by the natives as a cross.
Dun coat *Yellow coat*	Lightly pigmented hide.

Mixed colours:

Black and Tan or *Tan and Black* *Brindle*	Pigmentation dark.

Colour patterns:

Nhlophekati	Black pigmentation of the hide with a white coat. Regarded as the basal pattern.
Incawana	Spots or blobs of colour on basal pattern.
Mpunga	Numerous spots or flecks of colour on basal pattern.
Masavutshiwe	Localized flecks and fine spots.
Nkone	This pattern is also reported to have been prevalent in the Hamitic Longhorns. Colour panels with white top and underline. This pattern 'represents the final build-up of colour on the basal Nhlophekati pattern' and is much liked by the Swazi [15].
Inala	Not related to the basal pattern. The Swazi word 'M'bala' would appear to belong here as it describes an animal with coloured topline, a white belly and white legs. 'The colour pattern is one of black, red and brown indiscriminately mixed in irregular areas' (Bisschop 1945–6, unpublished report). However, this description of 'M'bala' is interpreted in a different way by the Swazis on Mpisi, who apply it to the animals having the Nhlophekati pattern. The Mpisi records would seem to bear this out, as no 'Nhlophekati' colour is recorded while 'M'bala' is.

There are numerous terms used by the Bantu to describe variations of the above patterns, but the attempt by the Committee to obtain a logical system resulted in the above broader classification, which includes these 'sub-patterns'.

General Usefulness of the Nguni Breed [4, 13, 14, 15, 16]

The Report of the Committee summarizes the Nguni's value to its owner, thus: 'As a source of food, cattle are primarily kept for the production of milk, and are occasionally slaughtered for special festive ceremonies. Cattle that die from natural causes are consumed and as such, constitute an important source of food.

'The hides are used for the making of shields.

'The oxen are used for draught purposes.

'One of the most important roles that cattle play in the lives of the Zulu and Swazi is as a means of payment for their wives in accordance with the custom of "lobolo".'

Nguni cattle play a very important part in the Natives' tribal life, exerting marked financial, religious, and social influence.

Merit has little place in the Zulu or Swazi's herds generally, but the larger the number of cattle owned, the greater is the owner's influence and social standing.

Nguni cattle possess very promising potentialities for milk production. The average milk yield has been estimated to be about 2 gallons daily off the veld, when the cows were in full milk-flow Curson states that the cows 'if properly selected and managed, are fair milkers, for even under Native management, odd animals yield a gallon of milk per diem'. There would appear to have been an improvement in the milking capacity of the Nguni over a 12-year period in Zululand.

Heifers seem to reach sexual maturity at about 2 years and seldom calve before they are about 3 years of age. Longevity would appear to be another characteristic of this breed.

There is little information about the Nguni as a beef producer, but for the Mashona, a close relative of the Nguni, steers off the veld near Salisbury and under free-range conditions on a European-owned farm, have been reported to weigh on the average 520 lb. cold dressed weight at the age of 3½ years. They are small boned and have a good beef conformation.

Nguni hides appear to be renowned with hide merchants, since they are fine textured and tough.

Female breeding stock have been much used by European farmers for cross-breeding with exotic breeds, in order to build up herds at low cost, and also to introduce a certain degree of hardiness. In the coastal belt of Natal the Nguni has been found to be an excellent draught animal.

Since the Nguni is found in large numbers in the Native areas, and has a certain degree of resistance to tick-borne diseases, it has been recommended that the mixing of blood should be arrested in the Native areas. Such a policy is readily understandable since, out of a total of 420,000 breeding cows in Swaziland and Zululand, only about 84,000 are typical Ngunis.

Some Breeding Statistics

The following observations are based on the Nguni herd maintained on the Mpisi Experimental Station, near Bremersdorp, Swaziland. In June 1951 the Nguni population of Mpisi was 804, the herd comprising 185 bulls, and bull calves, 141 oxen and 478 females, 266 of the latter being over 3 years of age. The foundation cows, over 200 in number, were obtained from their Swazi owners during late 1945 and during 1946. Apart from general characteristics, the shape of the head and horns were used as an index of purity in the course of selection [17]. The data here presented have been extracted from the Mpisi Station records.

Calving Rates

Table 2 shows the fertility data for 10 bulls up to the year 1954 inclusive. The data are based on the number of calves born to a group

of cows running with the bull for 3 months of each year in the breeding season.

TABLE 2. *Fertility Levels of Ten Nguni Bulls*

	Year							
Bull no.	*1948*	*1949*	*1950*	*1951*	*1952*	*1953*	*1954*	*Mean per bull*
	%	%	%	%	%	%	%	%
1	33	97	75	90	38	96	74	72
6	45	86	86	89	69	86	56	74
7	..	75	77	86	45	95	71	75
22	..	..	..	90	50	81	..	74
206	67	78	70	..	..	..	..	72
332	53	..	..	..	..	..	..	53
333	71	97	65 (*c*)	83	..	..	..	79
334	..	..	72	..	..	..	..	72
355	59	76	55	..	..	..	..	63
356	21	50	..	40	..	..	..	37
Yearly mean	50	80	71	80	51	90	67	

(*c*) = corrected for 'shy breeders'

The low figures appear to be generally attributable to a number of 'shy breeders' or sterile cows not confirmed as such in their first breeding year at Mpisi, but which were subsequently discarded from the breeding herd. From the figures in Table 2 the overall calf-crop appears to be in the vicinity of 68 per cent.

Calving Seasons

Natural. The cattle figures recorded at communal dipping tanks situated near Mpisi under fairly similar conditions are represented below in Table 3. The calf-increases for each dipping-tank area are recorded each month, and since the bulls run with the cows and heifers the whole year round, a reliable estimate of the natural calving season is derived. The figures are of 'total cattle population' and not of 'total female breeding stock' which would be of greater overall value. The figures are averaged over the years 1946 to 1952.

The greatest number of calves were dropped during the months November, December, and January, and this indicates a mating season during the period February, March, April, and May.

Controlled. Prior to 1951 only one mating season was practised at Mpisi, extending from 15 January to mid-April. A double breeding season was introduced in 1951, the periods corresponding to the equinoctial times of the year, as recommended by Bonsma [19, 20].

Although the winter calves weighed less than the summer calves up to approximately 6 months of age, from about 9 up to 24 months the reverse was true. These data refer to all female calves born during 1952 at Mpisi, and show the depressing effect on summer-born calves when they enter the winter period.

TABLE 3. *Total Number of Calves Born in Four Dipping Areas of Altitude and Climatic Conditions Similar to those Experienced at Mpisi, where no Breeding Control is Exercised, 1944–52* [17]

Year	*1944*	*1945*	*1946*	*1947*	*1948*	*1949*	*1950*	*1951*	*1952*[1]	*Total*
Total cattle population	*12,301*	*15,240*	*14,730*	*15,650*	*14,715*	*12,250*	*11,302*	*11,138*	*9,642*	*116,968*
Jan.	706	368	393	549	403	455	426	313	269	3,882
Feb.	381	205	417	270	344	244	220	125	238	2,444
Mar.	146	115	234	218	158	130	145	66	160	1,372
Apr.	141	115	128	140	107	88	72	57	66	914
May	118	60	80	95	62	68	69	30	65	647
June	76	48	67	98	72	60	69	23	101	614
July	119	55	62	96	105	36	83	39	134	729
Aug.	251	67	36	72	77	40	138	32	126	839
Sept.	335	171	49	120	87	52	182	18	164	1,178
Oct.	564	268	89	134	209	150	222	32	240	1,908
Nov.	554	404	286	646	468	360	355	258	347	3,738
Dec.	467	448	572	762	689	593	444	384	380	4,739
Total	3,858	2,384	2,413	3,200	2,781	2,276	2,425	1,377	2,290	23,004

[1] From Swaziland Veterinary Department.

TABLE 4. *Winter* v. *Summer Calves—Growth from Birth to 24 months, Expressed in Terms of Weight (lb.) (Female Calves)*

Age, months	*3*	*6*	*9*	*12*	*24*
Winter calves	Born June–July 1952				
No. in group	27	27	27	27	27
Mean wt. (lb.)	128·3	218·1	343·9	360·9	474·0
C.V. %	23·74	17·87	15·26	13·09	14·02
Summer calves	Born Jan., Oct., and Nov. 1952				
No. in group	40	41	33	41	40
Mean wt. (lb.)	162·8	241·4	253·0	286·9	432·6
C.V. %	16·83	11·56	12·22	14·66	10·67
t. test ('Student')	P = 0·01	P = 0·01	P = 0·01	P = 0·01	P = 0·01

Sexual Maturity

Under the Mpisi conditions Nguni males are reported to be sometimes capable of breeding at about 12 to 14 months of age, while the heifers appear to be able to breed at approximately 18 months. The Committee Report [6] states that 'under normal conditions, heifers seem to reach sexual maturity at about 2 years of age'. Heifers are normally put to the bull at about this age and parturition takes place just before 3 years of age. Young bulls are placed in service at about 3 years of age.

Birth Weights

Information is scarce on this subject, but from a few chance weighings of newly born Nguni calves, the weight of the heifer calves appears to be about 50 lb. Bull calves seem to vary in weight from about 55 to 60 lb. at birth.

Sex-ratio

Table 5 summarizes the data at Mpisi from 1945 to 1954.

TABLE 5. *Ratio of Males to Females Born at Mpisi over the years 1945 to 1954*

Total born	*Males*		*Females*	
	No.	%	*No.*	%
1,414	676	47·8	738	52·2

Twinning Frequency

Up to the end of the 1953/4 season three sets of twins had been born at Mpisi. In all cases they consisted of male and female pairs. This gives a frequency of 1 in 471.

Longevity

Very little recorded information is available. Of 157 of the foundation cows calving during the 1950/1 season, 70 were over 10 years of age, i.e. 44·6 per cent. Table 6 shows the age distribution of cows on Mpisi.

TABLE 6. *Estimated Age of Nguni Foundation Cows Calving During 1950/1*

Year of birth (est.)	*before 1938*	*1938*	*1939*	*1940*	*1941*	*1942*	*1943*	*1944*
Approx. age (yrs.) . .	Over 13	12–13	11–12	10–11	9–10	8–9	7–8	6–7
No. of cows calving in each age group	2	4	21	43	32	14	21	20
As % of total . . .	1·3	2·6	13·4	27·4	20·4	8·9	13·4	12·7

The Report of the Committee [6] states that 'in addition to the regularity with which these cattle calve, one of the most interesting observations recorded was the large percentage of old cows, obviously 15 years and older, which were to be seen in most herds'.

Discussion

Based on observations made by the Committee [6] and at Mpisi, the Nguni is relatively slow maturing, has a fairly high to high fecundity, appears to twin once in about 471 births, lives and reproduces regularly up to over 15 years, and calves at the highest rate over the months November to February.

In the Belgian Congo the cattle population, which includes Sanga, Afrikaner, and European breeds, is reported to have a birth rate between 72 and 75 per cent. [21]. Having regard to environmental differences, this compares favourably with 68 per cent. for the Nguni breed at Mpisi. Nyasaland reports indicate the calving percentages as being 67·5 to 80 for the Short-horned Zebu, while for the Afrikaner herd it was 67. Faulkner [22] claims over 75 per cent. calving rates for the Nandi and Boran in Kenya.

With regard to calving seasons, the peak months under 'natural' conditions are November to January inclusive, when approximately 53 per cent. of the calves are born. Thus under controlled conditions it would be wiser to breed accordingly.

While the Nguni heifers in Swaziland and Zululand are slow-maturing sexually (calving at about 35 months), compared with European breeds in their home environment, they are apparently earlier maturing than other African breeds, e.g. the Bukedi (about 41 months) [23], and the Boran (about 38 months) [22].

The environmental conditions for these different breeds will naturally determine not only the growth rates but the age at which the first calving is possible. An adequate nutritional level coupled with sound management of these indigenous breeds will allow of more favourable comparison with the exotic breeds as far as growth and reproduction are concerned.

The sex-ratio for the Mpisi Ngunis (i.e. 47·8 per cent. males and 52·2 per cent. females) is dissimilar to that found by Williams and Bunge [23] for Bukedi calves (52 per cent. males and 48 per cent. females). No twinning was reported among the 583 Bukedi births.

Acknowledgement

The writer wishes to acknowledge the help received from the Swaziland Veterinary Department.

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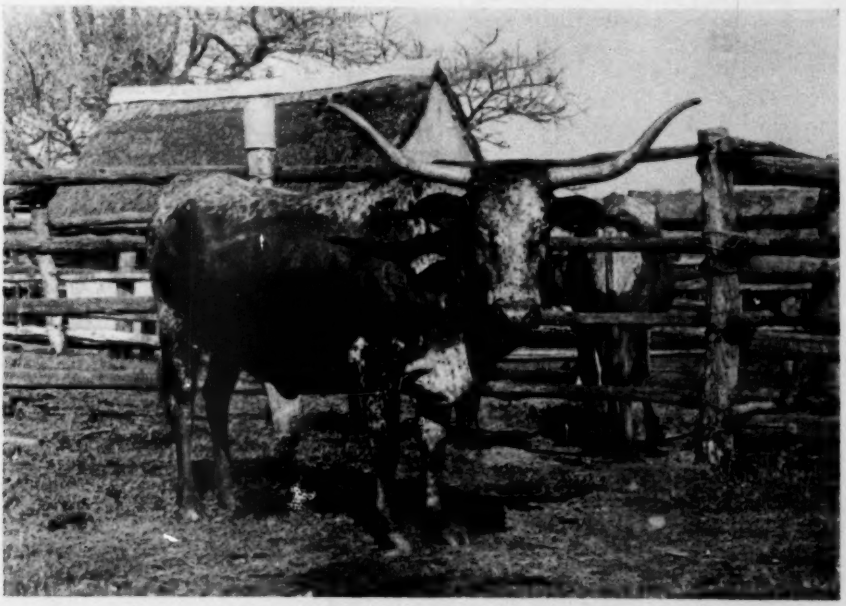
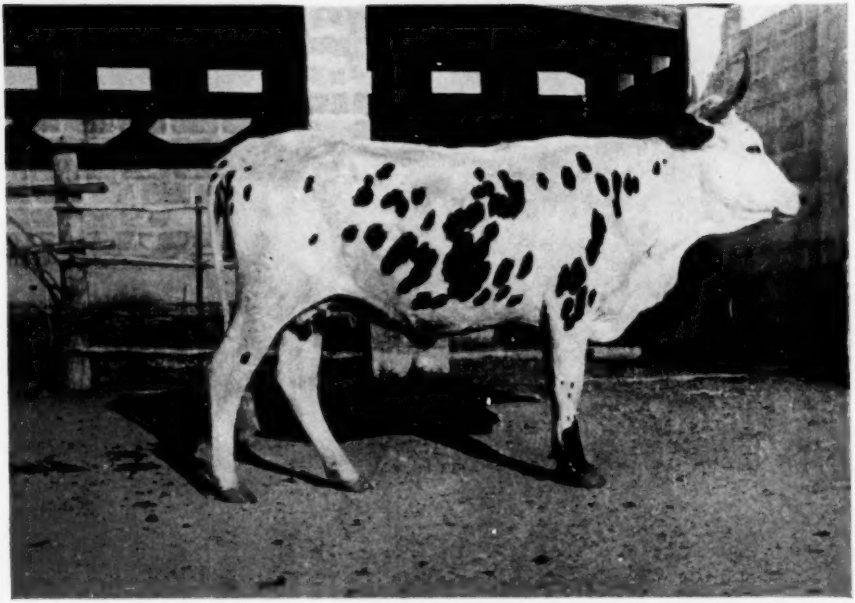
(*Received March–May 1957; revised June 1959*)

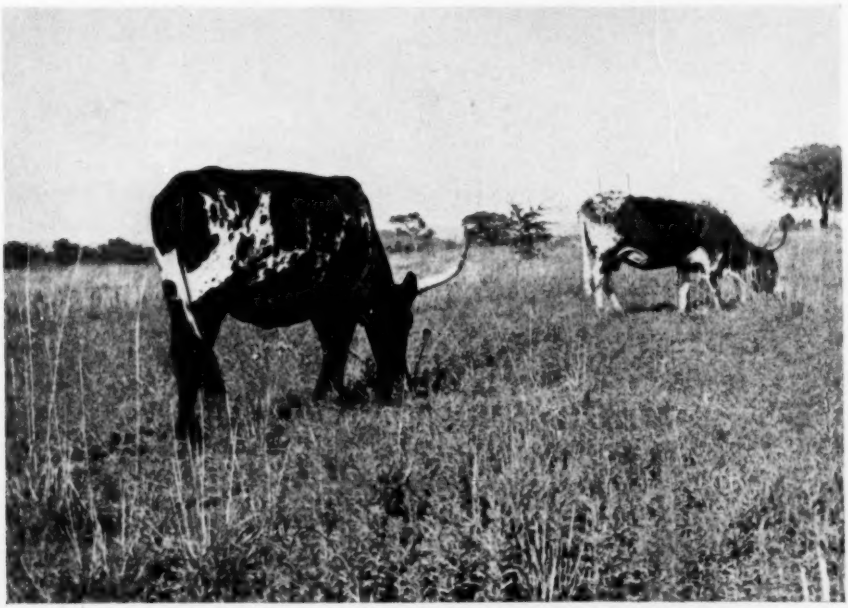
(*a*) 'Malinda II', 9 years of age when this photo was taken. An excellent Nguni bull.



(*b*) A typical Nguni cow showing the 'wide-apart' horn variation.



(*a*) An Nguni cow showing the 'Incawana' colour pattern. Note the lyre-shaped horns.



(*b*) Nguni cattle grazing on the Mpisi Experimental Station, Swaziland.

SEED RATES OF GRASSES FOR SEED PRODUCTION. I. PASTURE VARIETIES OF RYEGRASS, COCKSFOOT, AND TIMOTHY

GWILYM EVANS

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Summary

Seed of leafy varieties of perennial ryegrass, cocksfoot, and timothy sown in wide drills at *one* pound per acre produced yields as good as, or better than, those sown at the standard rate. Higher seed rates depressed seed yields of cocksfoot more than of the other two species and the harmful effect continued for four harvests.

Nitrogen converted barren tillers into seed-bearing stems and reduced the harmful effect of heavy seed rates on seed yields, especially in ryegrass. A combination of a low seed rate and nitrogen produced significantly better yields in cocksfoot and timothy than the other treatments.

The weight per 1,000 seed was not affected by seed rate; it declined with the age of the stand, and tended to increase with nitrogen applications.

The lowest rate saved valuable seed, made harvesting easier, and in cocksfoot and timothy produced better seed yields.

SEED rates of wheat, oats, and barley do not appear to have changed greatly in Britain for a thousand years; in medieval times the accepted optimum rates per acre were 2 bushels of wheat, 3 of oats, and 4 of barley. It was recognized then that medium to low rates gave the heaviest yield of grain; the need for low plant densities for root crops and forest trees has also been appreciated for many years. On the other hand, sowings in terms of *bushels* per acre have in the past been used in pasture making; the aim was to ensure maximum cover in the shortest time, as in lawn making. Later on ley mixtures were designed in *pounds* of seed per acre, and with the advent of leafy varieties the optimum poundage per acre was reduced very considerably.

It has been shown [1, 2] that the apparent inconsistency of making leafy varieties produce seed abundantly can be resolved to a great extent by using suitable techniques, but the seed rates of 4 to 6 lb. per acre normally used for wide-drill sowings are empirical, and information on their effects on seed yield seemed desirable. The results reported in this paper refer to high-tillering, late-flowering types of perennial ryegrass, cocksfoot, and timothy.

Methods

The experimental design was a Latin square for each of the species, eight treatments being applied, the gross plot consisting of four drills each 9 ft. long.

Seed of perennial ryegrass (S 23), cocksfoot (S 143), and timothy (S 48), was spring-sown in drills 24 in. apart, without a cover crop, at 1, 5, 25, and 125 lb. per acre respectively; seed crops were taken from three harvests of the ryegrass and four of the other two species.

[Empire Journ. of Exper. Agric., Vol. 27, No. 108, 1959.]

As the effect of nitrogen was also to be studied, the nitrogen-treated plots received the following quantities of Nitrochalk (15·5% N) per acre, applied in autumn and also again in spring: perennial ryegrass, 4 cwt.; cocksfoot, 4 cwt. for first harvest, and 6 cwt. for each subsequent harvest; timothy, 4 cwt. for first harvest, 5 cwt. for each subsequent harvest.

The soil was a medium loam of moderate fertility and rather shallow, so that high seed yields of leafy strains could not be expected to be maintained in a succession of harvests. The density of the seedings can be appreciated from the following data.

Seed rates (lb. per acre)	*Approximate number of seeds sown per linear inch of drill*		
	S 23	*S 143*	*S 48*
1	1	2	6
5	5	10	30
25	25	50	150
125	125	250	750

The higher rates of seeding were chosen for a collateral study, but the results from the whole range are considered to be of significance to the seed grower.

Results

The thin seeding of each variety showed 5–10 per cent. blank spaces in the early stages, but these were less noticeable in the nitrogen plots and after the sowing year; there was little difference between the weed content of the plots grown from the low and the high rates, except in the ryegrass, which appeared more susceptible to competition from volunteer species.

Timothy showed exceptional response to the application of nitrogen; anthesis was accelerated and the crop ripened earlier, a reaction which has appeared regularly in this species, but not in ryegrass or cocksfoot. Nitrogen caused a slight delay in maturation in the first harvest year crop of cocksfoot but thereafter no difference was observed.

In the autumn of the sowing year a sharp contrast occurred in the colour of the drills; the thicker seedings were yellow-green whereas the less dense stands were darker green and the plants more robust. The heaviest seeding produced earlier heading in the first harvest year of the ryegrass which received no nitrogen. The growth from the thin sowing of each of the species was the most widely spread in the drills and also the deepest green, and as there was more opportunity for tillering heading tended to be late. Aphid infestation appeared in the first harvest year and was heavier on the thickest seedings of ryegrass than on the thinnest.

Crops from the most dense sowing of ryegrass had the best standing power while cocksfoot at all rates showed little sign of lodging after applications of 6 cwt. Nitrochalk per acre. On the other hand, timothy receiving dressings of 5 cwt. was apt to lodge severely and it would appear that this level of nitrogen applied to timothy was excessive in a

region of relatively high annual rainfall of more than 40 inches. May and June of the third harvest year were so exceptionally dry and warm that the development of the timothy seed crop was restricted in a marked degree, yet with applications of 5 cwt. of Nitrochalk per acre the crop lodged at maturity following heavy rainfall in July and August.

The mean fertile tiller numbers per ft. length of drill for one or more harvest years were as follows (Table 1):

TABLE 1. *Mean Fertile Tiller Numbers produced per 12-inch Length of Drill at Various Seed Rates and Fertilizer Treatments*

		Seed rates (lb. per acre)											
	Harvest	*Without nitrogen*					*With nitrogen*					*L.S.D.*	
Species	*year*	*1*	*5*	*25*	*125*	*Mean*	*1*	*5*	*25*	*125*	*Mean*	P = 0·05	P = 0·01
† Perennial ryegrass S 23 .	1	179	193	167	130	167	259	264	259	223	251	30·2	40·3
† Cocksfoot S 143	1, 4	40	31	23	19	28	51	45	37	29	40	7·3	9·8
† Timothy S 48 .	1, 3, 4	99	105	84	80	92	120	127	119	100	116	9·4	12·6
Mean . .		106	110	91	76	96	143	145	138	117	136		

† Significant differences at P = 0·01.

The highest seed rate produced significantly fewer flowering stems than the lowest in each of the varieties and in every instance the heaviest rate also produced the fewest inflorescences, although the reduction was not always statistically significant. Significant differences were not found between the numbers from the 1-lb. and 5-lb. rates in ryegrass and timothy. In cocksfoot, however, the effect of seed rate with or without nitrogen shows a clear downward gradient.

Nitrogen has significantly increased the density of seed heads for all seed rates in each variety, the increment being relatively larger at the highest rates; the mean response was least in timothy. The relationship between fertile and barren tillers from the third harvest of S 48 timothy is shown in Table 2.

TABLE 2. *Numbers of Fertile and Barren Tillers of S 48 Timothy per 12-inch Length of Drill (third harvest year)*

	Seed rates (lb. per acre)											
	Without nitrogen					*With nitrogen*					*L.S.D.*	
Tillers	*1*	*5*	*25*	*125*	*Mean*	*1*	*5*	*25*	*125*	*Mean*	P = 0·05	P = 0·01
† Fertile .	72	68	52	47	60	110	123	118	103	114	17·1	22·9
† Barren .	58	63	82	82	71	21	27	31	29	27	10·1	13·4
Total .	130	131	134	129	131	131	150	149	132	141		

† Significant differences at P = 0·01.

Without nitrogen the numbers of barren tillers increased and fertile tillers decreased as the seed rate was augmented, the fertile tillers predominating at the lower rates and barren tillers at the higher. Nitrogen has effected a remarkable degree of conversion of barren into fertile tillers, so that the mean number of seed-bearing stems was over four times the mean number of vegetative shoots instead of there being a predominance of the latter.

A much greater relative response to nitrogen was made on the plots with the higher seed rates. The aggregate numbers of barren and fertile shoots were not appreciably increased, but stemmy crops, more like a cereal crop, were produced with the help of the fertilizer. In this experiment the two factors which stimulated the production of seed stems at the expense of barren shoots were (1) low seed rate and (2) nitrogen.

It was particularly obvious in the field that in the plots which did not receive nitrogen a very large proportion of the early shoots remained barren after an unusually dry May and June. After normal summer rainfall in the fourth harvest year, however, about twice the number of seed heads were produced on the same no-nitrogen plots as after the dry summer.

TABLE 3. *Seed Yields (lb. per acre) from Different Seed Rates for Various Harvest Years*

	Harvest year	Seed rates (lb. per acre) Without nitrogen 1	5	25	125	With nitrogen 1	5	25	125	L.S.D. P = 0·05	P = 0·01
Perennial ryegrass S 23	1	968	887	686*	582†	1,189	1,192	1,046	989*	164·3	219·7
	2	257	255	204	209	553	618	659	670	86·1	115·2
	3	57	50	52	55	83	83	87	96	24·2	32·3
Mean .		427	397	314*	282†	608	631	597	585	65·7	87·8
Cocksfoot S 143	1	460*	367	233†	134†	820*	700	384†	257†	90·1	120·4
	2	247*	168	123	175	343	343	302	388	70·7	94·6
	3	144	99	82	82	340	292	298	261	47·3	63·3
	4	161†	106	103	58†	247	220	250	175†	32·6	43·6
Mean .		253†	185	135†	112†	437*	389	309†	270†	36·5	48·7
Timothy S 48	1	588*	487	454	464	953†	694	643	652	90·7	121·3
	2	253*	200	198	133†	227	217	230	212	47·4	63·4
	3	172	144	130	128	156	159	150	168	(32·6	43·6)
	4	184	192	165	176	283	296	283	301	73·0	97·5
Mean .		299*	256	237	225	405†	342	326	333	36·7	49·1
Mean of all varieties		326	279	229	206	483	454	411	396		

* Significant differences from standard rate (5 lb.) at P = 0·05.
† Significant differences from standard rate (5 lb.) at P = 0·01.
Analyses of variance indicated significant differences between the treatments at P = 0·01 except in S 48 third harvest year.

The general trend of the data in Table 3 indicates that the mean seed yields for all the harvests were reduced as the seed rates were increased. The 1-lb. seeding produced significantly better yields in cocksfoot and timothy than the standard rate; the difference was not significant in ryegrass. When the reaction of yield to rate is compared for the different harvest years it will be seen that the greatest effect of seed rate occurred in the first harvest year and that it was sustained longer in cocksfoot than in either perennial ryegrass or timothy. The heaviest rates imposed a greater depressing effect on the mean seed yields of cocksfoot than on the other species.

When the means of the harvests are considered, nitrogen has produced a significant increase throughout, although the magnitude of the difference varied with the season, and has tended to reduce the effect of seed rate. Cocksfoot showed the greatest mean response and timothy

the least, although in the latter there was also a considerable increase. Furthermore, timothy yields were least affected by seed rate when nitrogen was withheld. Seeding at the heaviest rate has given the greatest relative response to the fertilizer, but there are no significant differences in the mean yields of ryegrass from the different seedings and all the harvests when nitrogen was applied. On the other hand, the top dressing has only partially corrected the depressive effect of high seed rates on cocksfoot and timothy.

Extreme contrasts in the effects of the treatments are seen between the columns for the 125-lb. seed rate without nitrogen and the 1-lb. rate with nitrogen. In the first harvest year cocksfoot produced more than six times the yield of seed under the latter treatment, and in ryegrass and timothy the yields were doubled.

Perennial ryegrass in the second harvest year showed an exceptional result in the rather higher yields from the heavier seedings when nitrogen was applied, the yield from the heaviest rate being significantly greater than that from the lowest. There is no significant difference between the mean values for the three harvest years; this suggests that a compensation for lower yields in the earlier crops occurred in subsequent crops.

The reduction in yield from the first to second harvest year was severe for each variety and is only partly explained by the first year being a more favourable season for seed production than the second; cocksfoot showed a steady decline over the 4 years. Ryegrass in the third harvest year failed to produce a reasonable crop on this class of soil. On the other hand, timothy was more resilient and showed a capacity for producing as good a crop in the fourth harvest year as in the second. The exceptionally dry early summer of the third harvest year severely checked the development of the timothy and ryegrass on this dry soil, hence the low seed yields. On the other hand, the wet June and July of the fourth harvest year militated against full pollination, fertilization, and seed development, with the result that a considerable proportion of the florets, especially of cocksfoot, failed to produce seed. The moderate rainfall in August was more favourable for the filling of timothy seed as shown by yield.

TABLE 4. *Fertile Tiller Numbers Compared with Seed Yields, with Means at 100*

	Harvest year	Seed rates (lb. per acre)									
		Without nitrogen					With nitrogen				
		1	5	25	125	Mean	1	5	25	125	Mean
S 23 Fertile tillers	1	107	116	100	78	100	103	105	103	89	100
Seed yields		124	114	88	75	100	108	108	95	90	100
S 143 Fertile tillers	1, 4	142	110	81	67	100	126	111	91	72	100
Seed yields		153	116	83	47	100	140	121	83	57	100
S 48 Fertile tillers	1, 3, 4	108	114	91	87	100	103	109	102	86	100
Seed yields		115	100	91	94	100	118	97	91	95	100

From the trend of the data in Table 4 it would appear that wider

differences occur in seed yield than in fertile tiller numbers as the result of the different treatments.

In order to determine whether treatments influence weight per 1,000 seeds, the seeds from the extreme rates of 1 and 125 lb. without and with nitrogen were compared for the different harvest years.

TABLE 5. *Mean weights (gm.) per 1,000 seeds*

Strain	*Harvest year*	*1 lb. per acre*		*125 lb. per acre*		*Means of treatments*
		Without N	*With* N	*Without* N	*With* N	
S 23	1	1·742	1·783	1·685	1·768	1·744
	2	1·560	1·613	1·570	1·683	1·606
Mean		1·651	1·698	1·627	1·725	
S 143	1	1·192	1·192	1·235	1·185	1·201
	2	0·950	0·966	0·941	0·996	0·963
	4	0·750	0·779	0·790	0·828	0·786
Mean		0·964	0·979	0·988	1·003	
S 48	1	0·290	0·302	0·285	0·305	0·295
	2	0·226	0·311	0·227	0·295	0·265
	4	0·232	0·228	0·241	0·236	0·234
Mean		0·249	0·280	0·251	0·278	
General Means		0·955	0·986	0·955	1·002	

The mean weights are remarkably even, and it would appear that seed rate extending over an extreme range did not exert a considerable influence on the weight of individual seeds (Table 5). Nitrogen showed a tendency to increase the weight, especially for timothy in the dry second harvest year.

The weights declined with the age of the stand; this is clearly shown in cocksfoot and is in sympathy with the successive reduction in yields per acre, although not nearly to the same extent.

Discussion

The process of adjustment of plant population may occur in thin stands through abundant tillering [3, 4] and in dense stands through loss of plants suffering from competition; it is recognized that competition is especially intense between plants of a similar type [5]. As the varieties used for this experiment were extremely high-tillering types, there was wide scope for adjustment at the lowest seed rate through tillering; on the other hand, adjustment at the thickest sowings was less successful. In maize [6] the percentage loss of plants increased with density, indicating that the process of adjustment was operative but not fully effective, the percentage of barren tillers having increased. Other workers have also found that barrenness increases with density [7, 8, 9].

Clements, Weaver, and Hanson [5] maintain that increased plant density leads to insufficient light for efficient photosynthesis, also to loss of chlorophyll and ultimately the death of the lower leaves; suppressed

plants make food very slowly, and densely populated plants may have negative root pressures. Brenchley [10] found that the overcrowding of barley encouraged shoot growth at the expense of root growth, resulting in decreased ability to use nutrients and consequently the production of fewer ears. The three varieties of grasses used in the present work exhibited similar depauperated symptoms with depressive effects on the seed yields.

Nitrogen exerts a levelling effect on vegetative yields of different varieties of grasses [11]. It has been shown by Gwilym Evans and Calder [1] that nitrogen is one of the most potent factors in promoting seminal reproduction in grasses and the evidence presented here shows that the heavier the seeding the greater the relative increase in seed yield brought about by the fertilizer for each of the species, thus effecting substantial levelling of the seed yields.

The tendency for a wider range of differences to occur in seed yield than in the corresponding tiller numbers seems to indicate that excessive seed rates reduce the seed yield of individual inflorescences more than their number; this was most pronounced in cocksfoot.

Previous results obtained at the Welsh Plant Breeding Station [12] have shown that sowing rates considerably below normal could be used for S 23 perennial ryegrass without affecting significantly the seed yields of the resultant crops; a sowing of 12 lb. per acre broadcast gave as satisfactory a yield as higher rates up to 36 lb. More recently, Lewis [13] has found no significant difference in yield when the sowing of S 23 was reduced from 12 lb. to as low as 4 lb. per acre broadcast with white clover as companion crop. Furthermore, Buller *et al.* [14] report that cocksfoot and timothy sown at 1½ lb. per acre in wide drills gave better seed yields than 3 lb. and in broadcast seedings 3 lb. was superior to 6 lb. Spencer [15] found that 3-lb. broadcast sowings of cocksfoot and tall fescue were superior to 7 lb. and 15 lb. In Holland the data of Evers and Sonneveld [16] indicate that relatively high rates depressed the seed yields of cocksfoot, timothy, and fescues.

The present studies have shown that for wide-drill cultures even a lower seed rate than that used by the workers quoted has given as good or better seed yields than the standard rates. Presuming that only one-third of the seed sown at the 1-lb. rate established plants there would have been per 3-in. length of drill one plant of ryegrass, two of cocksfoot, or six of timothy. Previous evidence at the Station [3] showed that cocksfoot plants spaced 12 in. apart in rows 2 ft. wide could produce better seed yields than drills sown at 2 lb. per acre. Therefore, in considering the optimum rate of seeding for these three leafy varieties it is possible that even the 1-lb. rate was excessive for the cocksfoot and timothy. An indication of this was seen in a 3-row-wide strip of spaced plants of these varieties planted 12 in. apart in 2-ft. rows alongside the experiment reported here. The most remarkable difference observed between seed crops of the spaced plants and those from the sown seed in the Latin square experiment was the comparatively few barren tillers in the former. Both the cocksfoot and timothy spaced plants appeared to grow more robust heads and fewer barren tillers throughout than those grown

from sown seed, and the crops stood better at harvest. Spaced plants and sown drills of tall fescue behaved similarly in another field.

It is clear from the data in this paper that the optimum seed rate for grasses varies with species; cocksfoot appears to be much more sensitive to seed rate than either ryegrass or timothy, even though three times the number of seeds of timothy were sown per unit length of drill. In contrast with cocksfoot and timothy, the ryegrass under the nitrogen treatment appeared to be capable of a remarkable degree of adjustment to a wide range of seed rates. Similar tolerance has been found in Wimmera ryegrass [7]; the range of densities over which near-maximum yields were recorded was very wide. Variation in plant density of maize also can occur without markedly affecting the grain yield because the plants can draw upon the soil fertility over considerable distances [17].

Maize has been found to produce better yields from a thin planting on poor land in a dry season but a thicker planting excelled on rich soil in a normal season [18]. The data from the present investigation tend to confirm these findings, and indicate that the use of heavy seed rates where the conditions for growth and development are poor involves a risk of substantial lowering of seed yields. A low seed rate, and also nitrogen, were found efficacious in producing better seed yields of leafy strains. Confirmation was obtained of the previously reported observation by Gwilym Evans [2] that nitrogen hastens anthesis and maturity in timothy.

Seed quality depends on several factors. A broadcast stand, for example, compared with wide drills has been shown [12] to reduce the seed weight per 1,000 seeds of perennial ryegrass S 23. The data submitted in this paper indicate that the age of the stand may affect the weight of individual seed to a considerable extent, and the tendency previously reported [1] for nitrogen to increase the weight is confirmed.

Density of the seeding in wide drills in the present study did not affect the mean weight per 1,000 seeds and confirms the results from broadcast stands of S 23 ryegrass sown at different rates [12].

In the first harvest year the hand-sieved seed of cocksfoot and timothy showed only slightly more weed seeds from the 1-lb. seeding than from the 125-lb. Perennial ryegrass, a shorter crop, had less shading effect on weeds and was harvested at a lower level, hence the inclusion of more weed seeds than in the other two species and in the thinnest stand the significantly greater amount of sorrel seed.

The main advantages derived from applying seed rates considerably below normal for seed production are (1) a saving of valuable seed, (2) earlier harvesting, and (3) better seed yields from some species.

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FERTILIZER PLACEMENT FOR SWEDES AND TURNIPS

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Summary

Field experiments were carried out over a period of 8 years to compare the effectiveness of fertilizers placed in narrow bands in various positions near the seed, with normal broadcast application.

Placement of ammonium sulphate to the side of the seed row gave results similar to broadcasting, but placing it in bands directly below the seed sometimes reduced both yield and stand, especially in dry weather.

The best position for placing superphosphate was directly below the seed at a depth of about 3 to 3·5 in. Placing low to medium amounts of phosphate in this position generally gave substantially higher yields than broadcasting, particularly on soils derived from basic igneous rocks. Placement to the side of the row was appreciably inferior to bands directly below the seed but was often superior to broadcasting. The apparent recovery of phosphorus from the fertilizer was substantially higher with placement, especially from bands directly below the seed.

In these experiments there was no advantage or disadvantage from placing muriate of potash at a depth of 3 to 3·5 in. directly below the seed.

There was no interaction between the broadcasting and placing of superphosphate and muriate of potash. It is not advisable to place a mixture of sulphate of ammonia and muriate of potash, supplying 40 lb. N and 100 lb. K_2O per acre, directly below the seed but placement at 2 in. to the side of the seed was safe and gave similar results to broadcasting.

Placing NPK mixtures either below or at the side was superior to broadcasting only on some soils, such as those derived from basic igneous drift, where placement of superphosphate was markedly superior to broadcasting.

DURING the past few decades the beneficial effects from placing plant nutrients, particularly phosphate, in bands near the seed of a number of crops have been demonstrated. In Scotland swedes and turnips, which are two of the principal crops used for feeding stock during the winter months, are normally grown in ridges. Generally fertilizer is broadcast on the flat cultivated land immediately before the ridges are raised. This ensures that it is concentrated to some extent in the centre of the ridge where the roots develop. Although the effects of placing fertilizers near the seed of root crops have been examined by a number of workers [1–4], there appears to be very little data for swedes and turnips grown in ridges. Field experiments were undertaken to study the effects, on germination and growth, of both single-nutrient and mixed fertilizers placed in bands in various positions near the seed, and to determine whether band placement is more effective than broadcast application. Some of the results from this investigation have already been published [5, 6] and the purpose of the present paper is to present the final conclusions.

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Experimental Details

Soils

During the period 1949 to 1956, fifty field experiments were carried out on a typical range of soils in north-east Scotland. Apart from two experiments on land derived from marine sand, the experiments were distributed over soils formed from glacial drifts of varying geological origin including Old Red Sandstone, granitic, basic igneous, and metamorphosed (predominantly slate) parent materials.

Apart from the two sandy centres, the soils varied in texture from light to clay loams and all had total organic matter contents below 15 per cent. All the soils were acid with pH values between 5·1 and 6·2, and with readily soluble (2·5 per cent. acetic acid) calcium, phosphorus, and potassium contents ranging from 100 to 330 mgm. CaO, 2 to 26 mgm. P_2O_5, and 3 to 15 mgm. K_2O per 100 gm. air-dry soil.

Climate

The climate of the area is moderately humid and temperate. The annual rainfall is normally between 30 and 35 in. and is reasonably uniformly distributed throughout the year. The precipitation between 1 May and 30 September is generally between 12 and 17 in. except in abnormally dry years like 1955 when there was only 8·3 in. The maximum summer temperature is seldom above 80° F., and the lowest winter values are usually about 5° F., the mean daily temperature normally ranging from 37° to 55° F.

Field Technique

Two methods of fertilizer application were investigated: broadcasting on the flat immediately before raising the ridges, and placing in a single band in various positions near the seed, mainly at a depth of 3 to 3·5 in. below the soil surface, either directly below or at 2 in. to the side of the seed row. The special machine which was developed by the National Institute of Agricultural Engineering was used to place fertilizer in a narrow band about 0·75 in. wide and was a slightly modified model of that used and described by Cooke [4]. The drill sowed two ridges 28 in. apart, and had concave rollers between the fertilizer coulters and seeder units. An auxiliary gear-box was fitted to control the centre hopper, which was designed to deliver fertilizer equally to both ridges at the same time. This arrangement facilitated the study of the interaction effects between two types of fertilizer. The fertilizers studied were ammonium sulphate (20·6 per cent. N), ordinary powdered superphosphate (18 per cent. P_2O_5), and muriate of potash (potassium chloride containing potassium equivalent to 60 per cent. K_2O). To facilitate drilling the muriate of potash was mixed with 16·7 per cent. gypsum and dried. The drill was calibrated before commencing the experiments, to obtain the desired rates, and these were checked in all experiments by collecting and weighing fertilizer on the control or broadcast plots. The quantities of broadcast fertilizers were calculated to be as near the placed rates as possible; the differences were generally too small to affect the

comparisons. For instance, the mean low rate of broadcast superphosphate was 37 lb. P_2O_5, while the corresponding rate of placed superphosphate was 39 lb. P_2O_5. The number of treatments in an experiment ranged from twelve to eighteen and these were randomized in blocks with three or four replicates. The plots were always four drills wide and were normally 20 yards in length.

All the centres had been cropped with oats the previous year, and appropriate basal dressings of fertilizers were applied where necessary. Dung was ploughed in at only one centre, involving an experiment with superphosphate and a nitrogen/potash mixture. Experiments were laid down during May or early June and the crops were singled during June and July and inter-row cultivated according to normal practice. Observations were made on the growing crops, and in harvesting during the months of November and December due allowance was made for edge effects. The number of roots harvested in every plot was counted to determine the effect of treatment on final stand.

In all experiments the seed was sown at a depth of about 0·75 in., and throughout the paper all depths of fertilizer placement are taken from the soil surface. Therefore 0·75 in. must be subtracted from all depth figures to obtain the distance between the levels of seed and fertilizer.

Results

Broadcasting and placing the various fertilizers had practically no effect on the percentage of dry matter in the roots, which was normally between 9 and 11 per cent., and all yields are expressed as tons of fresh matter per acre.

TABLE 1. *Comparisons of Broadcast and Band Applications of Ammonium Sulphate*

Mean results from five experiments

	Broadcast			
Rate—lb. N	0	20	40	60
Yield—tons	14·9	16·6	20·1	19·5
% N in F.M.*	0·107	0·111	0·116	0·126
Uptake—lb.	35·6	41·2	50·7	55·5
	40 lb. N placed directly below seed			
Depth	1 in.	2 in.	3–3·5 in.	Mean
Yield—tons	18·4	18·9	19·6	18·9
% N in F.M.	0·118	0·117	0·116	0·117
Uptake—lb.	49·5	50·0	50·2	49·8
	40 lb. N placed 2 in. to side of row			
Depth	1 in.	2 in.	3–3·5 in.	Mean
Yield—tons	20·7	19·5	20·9	20·4
% N in F.M.	0·117	0·117	0·110	0·115
Uptake—lb.	54·4	50·4	50·6	52·8

* Throughout the tables F.M. stands for fresh matter and all rates, yields, and uptakes are per acre.

Sulphate of Ammonia—Table 1

Band placement of ammonium sulphate at a rate supplying 40 lb. N per acre was compared with normal broadcast applications at various levels. Placing this fertilizer at distances of 1 in. or more to the side of the seed had no injurious effects on brairding or early growth, but placing it directly below the seed sometimes reduced germination and retarded early growth. This effect depended on the distance between seed and fertilizer and on the rainfall; the smaller the distance between seed and fertilizer and the lower the rainfall during the 3-week period after sowing the greater was the injurious effect from band placement directly below the seed.

The number of roots in plots with bands of sulphate of ammonia at depths of 1 and 2 in. directly below the seed was generally smaller than in the other treatments. The mean yields in Table 1 show that broadcast nitrogen produced a moderate response and that at the 40 lb. N rate placement at depths of 1 and 2 in. directly below the seed gave slightly lower yields than broadcasting. At 3 to 3·5 in. directly below the seed, and at all three depths at 2 in. to the side, the yields were practically the same as those for the corresponding broadcast rate. The nitrogen content of the roots increased with increasing rate of broadcast nitrogen, but except for a slightly lower content from placing at the 3 to 3·5 in. depth at 2 in. to the side there were no appreciable effects of method or position of application. The uptake figures show that the apparent recovery with broadcasting was greater at the 40- and 60-lb. than at the 20-lb. level, and that the differences between the values for the corresponding broadcast and placed treatments were small and of no importance.

Superphosphate—Tables 2, 3, 4, and 5

There were twenty-nine experiments comparing the placing of superphosphate, at rates between 30 and 80 lb. P_2O_5 per acre in bands at depths of 3 to 3·5 in., with corresponding broadcast levels. Placing this fertilizer directly below the seed had a much greater effect in stimulating early growth than either broadcasting or placement to the side of the row; this was so marked at most of the centres that the plants were ready for singling about a week earlier. The growth of the young plants in plots with phosphate placed in bands at 2 in. or more to the side of the row was much slower and similar to the no-phosphate treatment. Early growth in the broadcast treatments was generally intermediate between no phosphate and band placement below the seed.

Broadcast phosphate increased the yield at all centres, the responses ranging from small to very large and being significant at nineteen centres. The number of roots lifted was sometimes increased by phosphate but there was no difference between the two methods. The mean results for the twenty-nine experiments in Table 2 show that the low level (30 to 40 lb. P_2O_5) placed at a depth of 3 to 3·5 in. directly below the seed gave an increase of 3·6 tons swedes per acre over the corresponding broadcast treatment.

Placing was never inferior to broadcasting, but there was a large

TABLE 2. *Comparisons of Broadcast and Band Applications of Superphosphate*

Mean results for groups of experiments involving various P_2O_5 rates and one or two placement positions

	Actual values	Response to broadcast P_2O_5			Increase from placing, over broadcasting			
					0 in. side		2 in. side	
P_2O_5 rate—lb. .	0	30–40	60–80	120	30–40	60–80	30–40	60–80
29 experiments								
Roots—tons .	13·8	5·0	7·1	..	3·6	..	..	..
% P_2O_5 in F.M.	0·049	0·003	0·007	..	0·001	..	..	..
Uptake—lb. .	15·2	6·5	10·5	..	4·0	..	..	..
24 experiments								
Roots—tons .	13·6	4·0	6·1	..	3·6	3·0	..	..
% P_2O_5 in F.M.	0·050	0·003	0·006	..	0·001	0·004	..	..
Uptake—lb. .	15·5	5·7	9·1	..	4·5	4·8	..	..
17 experiments								
Roots—tons .	13·8	5·6	7·4	8·8	6·0	..	1·6	..
% P_2O_5 in F.M.	0·047	0·003	0·007	0·013	0·000	..	−0·001	..
Uptake—lb. .	14·3	7·0	11·2	15·9	3·6	..	1·9	..
12 experiments								
Roots—tons .	13·4	3·6	5·5	7·0	4·2	3·4	2·0	2·0
% P_2O_5 in F.M.	0·049	0·004	0·006	0·012	0·000	0·003	−0·001	0·002
Uptake—lb. .	14·5	5·8	8·6	13·3	4·5	4·5	1·8	3·1

variation in the superiority of placing which depended not only on the responsiveness of the soil to broadcast phosphate but also on its type. At one centre on a granitic soil, which gave a highly significant response to phosphate, there was no effect of method of application at the low level. At two other centres on granitic soils (one with a significant response) and at three centres on slate soils (one with a significant response) the superiority of placing over broadcasting at the low rate was less than 1 ton per acre. At the remaining twenty-three centres band placement produced from 1 to 13 tons more roots per acre, the differences between the two methods being significant in ten experiments. The results in

TABLE 3. *Influence of Soil Parent Material on the Effectiveness of Phosphate Placement*

Mean yield results (tons) for the effects at 30 to 40 lb. P_2O_5

Parent material	*No. of experiments*	*Mean response to broadcast P_2O_5*	*Increase from placing, over broadcasting*	*Percentage superiority of placing*
Old Red Sandstone	9	7·4	3·8	51
Granitic . .	7	5·8	2·0	34
Basic Igneous .	6	4·6	7·6	165
Slate . . .	7	1·6	1·6	100

Table 3 show the marked influence of soil type on the method of application at the low rate. Band placement was greatly superior to broadcasting on the basic igneous group. This was also generally so on both Old Red

Sandstone and granitic soils, but the differences between the two methods were not nearly so large as that on the basic igneous group. The soils on the slate group were not so responsive to phosphate and therefore the comparison of the two methods was not so sensitive. It is, however, noteworthy that band placement on the slate group doubled the response and, on a percentage basis, was intermediate between the basic igneous soils and the Old Red Sandstone and granitic groups.

At the low rate both broadcasting and placing (Table 2) gave practically the same small increase in the P_2O_5 percentage in the roots. The apparent recovery of applied phosphate was nearly 18 per cent. for broadcasting and approximately 27 per cent. for placing. Compared with double the amount broadcast, placing 30–40 lb. P_2O_5 has given a slightly higher yield and a similar apparent recovery.

In twenty-four of the experiments (Table 2) there was a comparison of two rates broadcast with the same two rates placed at a depth of 3 to 3·5 in. directly below the seed. The superiority in yield for placing, over broadcasting, was slightly greater at the low than at the medium (60–80 lb. P_2O_5) rate. The effect of soil type was confirmed at the medium rate, the mean responses to placing being 33, 25, 91, and 51 per cent. higher than those for broadcasting on the Old Red Sandstone, granitic, basic igneous, and slate soils respectively. These are mean values for six experiments on each group and, although appreciably lower, place the four soil types in the same relative order as the results for the low rate in Table 3. Placing the medium rate, however, gave a slightly greater increase in the P_2O_5 content of the roots, with the result that the additional uptake of phosphate from placing was equally as great with the medium as with the low rate.

One rate of phosphate placed in two positions was studied in seventeen experiments (Table 2). Placing was better than broadcasting in both positions, but the superiority of the former was much greater with bands directly below the seed than at 2 in. to the side of the row. There was practically no difference in the phosphorus contents of the crops and the additional apparent recovery of applied phosphate from band placement directly below the seed was almost double that from placing at 2 in. to the side. Another interesting point from this group is that placing the low rate directly below the seed gave a slightly greater yield than 120 lb. P_2O_5 broadcast.

In the twelve experiments (Table 2) comparing placement at two rates in two positions, the superiority of bands directly below the seed was again obvious in both yield and uptake. With side placement, however, the additional yields were the same for both rates, but the apparent recovery was greater with the medium level.

Earlier experiments, reported by the author [5], had examined the effects of band placement in various positions up to 3 in. to the side of the row and down to depths of 3·5 in. below the soil surface. Two experiments on granitic soils were undertaken by hand to study bands at greater distances to the side of and below the seed. The results of one of these experiments are given in Table 4 and show a very large response to phosphate, which was applied at the same rate (80 lb. P_2O_5) for both

TABLE 4. *Comparison of Broadcasting Superphosphate with Placing in a Range of Positions*

Mean results for one experiment involving one rate of 80 lb. P_2O_5 per acre

	No P_2O_5	*Broadcast* P_2O_5	
		Flat	*Ridged*
Yield—tons	14·3	26·5	30·2
% P_2O_5 in F.M.	0·052	0·060	0·056
Uptake—lb.	16·7	35·6	37·9
% recovery	..	23·6	26·5

	Depth of band	P_2O_5 *placed in bands*				
		Distance of band to side of seed row				
		0 in.	*3 in.*	*6 in.*	*12 in.*	*Mean*
Yield—tons	3 in.	32·3	24·3	18·9	23·6	24·8
% P_2O_5 in F.M.		0·058	0·062	0·059	0·062	0·060
Uptake—lb.		42·0	33·7	25·0	32·8	33·4
% recovery		31·6	21·2	10·4	20·1	20·8
Yield—tons	6 in.	31·5	21·3	23·8	21·8	24·6
% P_2O_5 in F.M.		0·053	0·056	0·060	0·058	0·057
Uptake—lb.		37·4	26·7	32·0	28·3	31·1
% recovery		25·9	12·5	19·1	14·5	18·0
Yield—tons	12 in.	30·0	21·8	19·0	17·3	22·0
% P_2O_5 in F.M.		0·060	0·055	0·068	0·058	0·060
Uptake—lb.		40·3	26·9	28·9	22·5	29·6
% recovery		29·5	12·8	15·2	7·2	16·2
Yield—tons	Mean	31·3	22·5	20·6	20·9	..
% P_2O_5 in F.M.		0·057	0·058	0·062	0·059	..
Uptake—lb.		39·9	29·1	28·6	27·9	..
% recovery		29·0	15·5	14·9	13·9	..

broadcast and placed treatments. The mechanical operation of ridging the land after broadcasting this fertilizer has produced an appreciable, but not significant, increase in the effectiveness of the phosphate. (In the flat treatment the broadcast fertilizer was raked into the top 2 in. of the soil before sowing the seed.) With placement the main effect was the marked superiority of bands at all three depths directly below the seed. Although placement at 3 in. to the side of the row tended to be slightly better than at 6 in. and 12 in., the differences were very small and far from significant.

The P_2O_5 contents of the roots showed small differences which reflect the relative yields. The uptake figures showed quite a high apparent recovery from both flat and ridge treatments. Placement of the phosphate directly below the seed gave a considerably higher uptake than placement to the side, the mean apparent recovery for the former being 29 per cent. compared with about 15 per cent. for the latter.

The superphosphate used in the other experiment contained a proportion of radioactive phosphorus (P^{32}). This experiment was carried out in

1955 when there was only about half the normal summer rainfall, and the effects, on yield, of phosphate applied at the rate of 80 lb. P_2O_5 per acre were not typical. During the growing season the leaves and roots of the swede plants were analysed at various stages for total phosphorus and P^{32}, and the results for the roots are given in Table 5. The figures

TABLE 5. *Effect of Broadcasting and Placing Superphosphate on the Percentage of P_2O_5 in Roots derived from the Fertilizer, at various stages of growth*

Results from one experiment involving one rate of 80 lb. P_2O_5 containing P^{32} per acre

No. of days from sowing		27	48	77	104	122
Broadcast		55	16	7	20	15
Placement (in.)						
Side	*Depth*					
0	1	71	79	48	39	57
0	3·5	62	69	70	49	65
0	6	54	77	74	56	78
2	1	57	74	59	54	55
2	3·5	65	79	64	58	70
2	6	12	74	70	64	36
4	1	12	56	48	43	56
4	3·5	8	73	52	52	45
4	6	10	73	67	60	62
6	3·5	0	66	50	42	65

for the leaves showed practically the same effects as those for the roots. With broadcast phosphate, in early growth about half the phosphorus in the plant came from the fertilizer. The proportion of fertilizer phosphorus in the swedes fell rapidly as the period of growth lengthened and, when the crop was approaching maturity, only a small percentage of the phosphorus in it had come from broadcast superphosphate.

The results for band placement show that the advantage in final yield arose from the fact that during early growth the plants could obtain more phosphate from bands near the seed. At 48 days after sowing about two-thirds to three-quarters of the phosphorus in the swede plants had come from the fertilizer irrespective of the position of placement. There was a slight decrease in the proportion of fertilizer phosphorus in the crop as it approached maturity but about half the amount in the roots was still derived from the superphosphate in all the placed treatments compared with only 15 per cent. from broadcasting. Since the results refer to only single-treatment samples from one experiment no importance is attached to the smaller variations.

Muriate of Potash—Table 6

Broadcast and band applications of muriate of potash were compared in sixteen experiments at rates supplying from 50 to 120 lb. K_2O per acre. There was no indication that placement in bands at a depth of 3 to

3·5 in. directly below the seed had any effect on germination and early growth. The number of roots at lifting was also unaffected by the method of application.

TABLE 6. *Comparisons of Broadcasting and Placing Muriate of Potash*

Mean results for groups of experiments involving various rates and one placement position at depth of 3 to 3·5 in. directly below the seed

	Actual values	*Response to broadcast* K_2O		*Increase from placing, over broadcasting* K_2O	
K_2O rate—lb. . .	0	50–60	100–120	50–60	100–120
		8 experiments			
Roots—tons . .	16·2	4·2	5·2	−0·3	..
% K_2O in F.M.. .	0·20	0·04	0·08	0·01	..
Uptake—lb. . .	68·3	30·6	59·0	5·3	..
		12 experiments			
Roots—tons . .	19·0	..	2·8	..	−0·5
% K_2O in F.M.. .	0·22	..	0·07	..	0·00
Uptake—lb. . .	100·0	..	49·3	..	−7·2

At two centres the yield was not increased by broadcasting but in the others 100–120 lb. K_2O produced increases in yield ranging from 1·5 to 14 tons per acre, the responses being significant in eight experiments. In the eight trials where comparisons at the lower rate (50–60 lb. K_2O) were made none of the differences between the two methods was significant and, as the mean yields in Table 6 show, there was practically no difference between them. The small decrease from placing arose from two experiments where this method was slightly inferior but at the other six centres there were small increases from band placement.

At the higher rate (100–120 lb. K_2O) placing gave significantly lower yields at two centres and in six experiments there were small decreases. In one experiment there was no difference between the two methods and in three there were small but not significant increases. The mean results in Table 6 for the higher rate show a small decrease with placing and reflect the general trend for band placement at this rate to be slightly inferior to broadcasting.

Broadcasting increased the potassium content of the bulbs and the uptake figures show an apparent recovery of the order of 50–60 per cent. Placing the potassic fertilizer had no effect on the percentage K_2O in the bulbs. It has given a slightly greater uptake at the lower rate, but a smaller uptake at the higher rate.

Interaction of Phosphorus and Potassium

The interaction between broadcasting and placing superphosphate and muriate of potash was measured in twelve of the above experiments involving both fertilizers. The magnitude of this effect ranged from −1·2 to +1·8 tons roots but there were no significant effects, the mean value

being 0·2 tons per acre. There is no indication that the method of application produced any interaction effects in the phosphorus and potassium contents of the roots.

Mixture of Ammonium Sulphate and Muriate of Potash

Broadcasting a mixture of these two fertilizers, supplying 40 lb. N and 100 lb. K_2O per acre, was compared in twelve experiments with band placement at a depth of 3 in. in two positions, one directly below the seed and the other 2 in. to the side of the row. Except at one centre where there was a small but not significant increase, placing directly below the seed gave lower yields than broadcasting, the decrease in yield being significant in one experiment. In this position the mean yield was 1·4 tons less than that from broadcasting. At 2 in. to the side of the row the effects were more variable, none being significant, and the mean value shows a very small decrease of 0·4 tons per acre. There were practically no differences in the N, P_2O_5, and K_2O contents of the roots attributable to the methods of application.

NPK Mixtures

In twelve experiments comparisons of broadcasting two mixtures of ammonium sulphate, superphosphate, and muriate of potash supplying 35 and 70 lb. P_2O_5, each with 40 lb. N and 100 lb. K_2O per acre, were made with band placement in the same two positions as for the nitrogen–potash mixture above. Except at one centre where there was a decrease, placing the mixtures directly below the seed gave from 0·0 to 5·4 tons more roots than broadcasting, the mean increase being 1·8 tons. This mean value arises largely from four experiments where the superiority of placement ranged from 3·5 to 5·4 tons, three of the centres being on basic igneous soils and the fourth on Old Red Sandstone containing andesitic lava. In another experiment placing directly below the seed produced 2 tons more roots than broadcasting and at the remaining six centres the superiority of band placement was less than 1 ton.

At 2 in. to the side of the row the differences between the two methods were very similar and ranged from −0·8 to +6·2 tons. The mean was 1·4 tons and was again mainly attributable to the three basic igneous centres where the superiority of placement ranged from 2·5 to 6·2 tons.

The N, P_2O_5, and K_2O contents of the roots were practically unaffected by the three methods of application and the uptake values for these nutrients reflected the yield effects.

Discussion

It was quite safe to place ammonium sulphate in narrow bands at distances of 1 to 3 in. to the side of the seed row, but this method of application did not increase its effectiveness. Placing this fertilizer directly below the seed may retard brairding and reduce both plant stand and yield, particularly if a dry spell follows seeding. These experiments show no advantage in placing ammonium sulphate.

The results in this paper and those reported previously [5, 6] clearly

show the superiority of placing superphosphate in narrow bands directly below the seed; the best depth was about 3 to 3·5 in. below the soil surface or about 2·5 in. below the seed. Placing to the side of the seed was inferior and the reason for this appears to be that the phosphate was not in a position where the very young swede and turnip plants could use it. The importance of an easily accessible supply of 'available' phosphate is demonstrated by the observations that early growth was best in plots with bands directly below the seed. Although the crop appeared to take up the same proportion of fertilizer phosphorus from side bands, the phosphate was not in a position where it could be utilized during the important stage of very early growth. Although there was an effect of depth of placement below the seed it was relatively small. The young swede and turnip roots grew downwards very rapidly and at singling time could be traced to depths of at least 6 in.

The P_2O_5 percentage figures agree with the well-established finding that the phosphorus contents of swede and turnip roots increase with phosphate levels. Placing had practically no effect on the phosphorus contents of the roots but produced a substantial increase in the apparent recovery of the fertilizer phosphate. The results for the experiment with superphosphate labelled with P^{32} also show a large increase in the utilization of the fertilizer phosphorus and this agrees with the findings of other workers such as Olsen and Gardner [7]. The mean values for 30 to 40 lb. P_2O_5 show that, compared with broadcasting, placing at a depth of 3 to 3·5 in. directly below the seed gave about a 70 per cent. increase in yield and about a 60 per cent. increase in the utilization of the fertilizer phosphorus. It is also clear that placing this low dressing will generally give at least as good a yield as broadcasting two to three times as much phosphate.

The effectiveness of placement, however, depends on both the responsiveness and the type of soil. The benefits of band placement were generally greatest on soils which gave large responses to and which were deficient in phosphate. This agrees with both the experimental findings and theoretical deduction of others [3, 8, 9]. Another important finding from the present trials is the influence of the geological nature of the parent material. It is quite clear that band placement was more effective on soils of basic igneous origin than on those formed from granite or Old Red Sandstone. This agrees with the general characteristics of these soil types described by Williams *et al.* [10] in that the basic igneous group have higher phosphate sorption capacities and higher iron and aluminium contents than the other two groups. Since placing produces a high local concentration it is reasonable to expect it to have a greater effect on soils with a high capacity to retain or sorb phosphate. Similarly this is probably an important reason why the actual responses to broadcast phosphate, on the other hand, were clearly higher in the Old Red Sandstone and granitic than in the basic igneous and slate groups. Although the centres on the slate group of soils were not very responsive to phosphate it is noteworthy that the superiority of band placement on a percentage basis was intermediate between the basic igneous soils and the other two groups. This also is in keeping with the findings of Williams [11].

The results of earlier experiments [5] show that it is not advisable to place potassic fertilizers containing appreciable amounts of sodium chloride near the seed, and that placing muriate of potash at 3 in. to the side of the seed is sometimes inferior to broadcasting or placing nearer the seed. The experiments reported here showed no advantage or great disadvantage in band placement near the seed. This agrees with the theoretical conclusions of De Wit [8], who observed that there is likely to be little benefit from placing nutrients with apparent recoveries of the order of 50 per cent.

There was practically no interaction between broadcasting and placing superphosphate and muriate of potash. It was quite safe to place potassic-phosphate fertilizers directly below the seed and this method of application is likely to increase their effectiveness.

It is not advisable to place a mixture of ammonium sulphate and muriate of potash directly below the seed. Placement at 2 in. to the side of the seed was safe and gave similar yields to broadcasting. This is doubtless attributable to the fact that both ammonium sulphate and muriate of potash are soluble fertilizers and, when placed in narrow bands in the region where young roots develop, the concentration of soluble salts restricts and retards growth. The experiments were not designed to determine which fertilizer was mainly responsible for this injurious effect, but it seems that ammonium sulphate is likely to contribute at least as much as, and probably more than, muriate of potash.

The results of a few earlier trials [5] showed no great advantage from placing NPK mixtures either below or to the side of the seed. The present series has confirmed that this finding applies to the majority of soils and that band application will be superior to broadcasting only where the effectiveness of superphosphate is substantially increased by placing. From the phosphate results it is clear that placing NPK mixtures can generally be expected to be appreciably better on basic igneous soils, but only occasionally on the other groups. It seems that with band placement the ammonium sulphate and muriate of potash in the NPK mixtures counteracted to a large extent the beneficial effects from phosphate. These findings do not agree with those of Cooke [4], who found a marked advantage from placement for swedes grown on the flat. This difference is almost certainly attributable to the partial placement effect of the ridging operation, which increases the effectiveness of broadcast fertilizers, especially phosphate.

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BIRTH, WEANING, AND YEARLING WEIGHTS OF RAHMANI SHEEP. I. EFFECTS OF SOME ENVIRONMENTAL FACTORS. II. HERITABILITY ESTIMATES, AND CORRELATIONS

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Summary

I. A study has been made of the effects of year, season of lambing, sex and type of birth, and age of dam, on weaning and yearling weights of Rahmani lambs.

Variation from each of the three main sources (sex and type of birth, year, and season) was highly significant for both weights.

Summer-born lambs excelled winter-born lambs in birth and weaning weights, but, after weaning, winter-born lambs grew faster than summer-born lambs, up to 12 months. Growth rates in all groups decreased after weaning.

The bearing of these results on husbandry and selection practices is discussed.

II. Heritability estimates for birth, weaning, and yearling weights of Rahmani lambs were 0·16, 0·18, and 0·19, respectively. The half-sib correlation (intra-class correlation) was used in estimating the heritabilities.

The phenotypic correlations among these weights were 0·212 for birth and weaning weight, 0·205 for birth and yearling weight, and 0·315 for weaning and yearling weight.

The method of path coefficients was used to determine the relative importance of birth and weaning weights as causes of variation in yearling weight; weaning weight was indicated as being twice as important as birth weight.

I. *Effects of Environmental Factors*

SELECTION programmes designed for sheep improvement lay much emphasis on both weaning and yearling weights. Weaning weight is highly correlated with market weight [1]. It is also correlated with yearling weight, which affects the pounds of lamb weaned and, to some extent, wool production per ewe year [2].

Only part of the variability in most economic characters is genetic, and the rest is caused by environmental factors. Knowledge of such factors helps in selecting animals with the highest breeding values. This first part of the present study is concerned with the effects of year, season of lambing, sex and type of birth, and age of dam, on weaning and yearling weights of Rahmani lambs.

The Data

There were 604 weaning and 465 yearling weights available for the present study, for lambs born during the period 1943 to 1956 on the Experimental Farm of the College of Agriculture, Alexandria University. Lambs born from March to August are referred to as summer-born, and those born from September to February as winter-born. About one-third of all lambs were summer-born, mainly in March, April, and May. The others were winter-born, mainly in October, November, and December.

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The sheep were fed on berseem (*Trifolium alexandrinum*) from November until May. In the summer they grazed in the fields and were given a ration of about ¾ kg. of concentrates (equal amounts of cotton-seed cake and rice bran). Weaned lambs also received some concentrates. For the last 5 years, Sweet Sudan grass was grown during the summer to supply green fodder.

Lambs were weighed within 24 hours of birth, to the nearest 0·1 kg., and then at monthly intervals. Weights for the years 1947, 1948, and 1949 have been excluded because the flock had been moved to another location and only a few weights could be taken during that period. Weights at 4 and 12 months were considered as weaning and yearling weights respectively.

Dams were classified into mature and 2-year-olds (ewes are usually fully grown by 2 years of age). Records of age were available for some dams only, and therefore the effect of their age on weaning and yearling weights was analysed separately. There were 104 weaning and 75 yearling weights available for that comparison.

Results and Discussion

The analysis of variance for weaning and yearling weights is presented in Table 1. Variation from each of the three main sources, namely: sex and type of birth, year and season, was statistically highly significant for both characters.

TABLE 1. *Analysis of Variance for Weaning and Yearling Weights*

Source of variation	*Weaning weight*		*Yearling weight*	
	d.f.	*Mean squares*	*d.f.*	*Mean squares*
Total	603	29·15	464	67·27
Type of birth	3	91·53†	3	1026·33†
Year within type	40	112·61†	40	111·68†
Season within year and type	37	70·32†	32	289·86†
Within season	523	19·49	389	36·99

† P = < 0·01.

Year. Table 2 presents the average weaning and yearling weights. Yearly fluctuations in lamb weights reflect variations in feeding and disease conditions as well as differences in the genetic and age composition of the flock. Asker *et al.* [3] found that between years there was a significant variation in weaning and 6-month weights of Rahmani lambs at Giza.

Season of lambing. The average weaning and yearling weights for the different months of the year are given in Table 3. Summer-born lambs were on average 0·70 kg. heavier than winter-born lambs, at 4 months, but at 12 months winter-born lambs were 0·60 kg. heavier than summer-born lambs. From weaning until 12 months of age, winter-born lambs were thus growing faster than summer-born lambs. To investigate

this change-over all available average monthly weights of lambs from 1943 to 1956 were studied. The results are shown in Figs. 1 and 2.

At birth summer-born lambs were slightly heavier. They maintained and even increased this superiority until 4 months of age. This was largely because ewes lambing in the summer season are usually in better condition than those lambing in the winter. They are on berseem during their gestation period and until the end of May. This helps them to

TABLE 2. *Effect of Year on Weaning and Yearling Weights*

Year	*Weaning weight*		*Yearling weight*	
	Number	*Avg. (kg.)*	*Number*	*Avg. (kg.)*
1943	39	18·7	24	37·5
1944	53	16·9	33	33·5
1945	56	16·2	37	35·8
1946	51	19·6	21	29·0
1950	31	21·9	25	37·3
1951	61	18·7	68	41·8
1952	73	23·6	84	39·5
1953	73	15·7	46	32·5
1954	61	17·6	39	34·3
1955	51	17·6	46	32·2
1956	55	19·3	42	31·6
Total or mean	604	18·6	465	35·9

TABLE 3. *Effect of Season on Weaning and Yearling Weights*

Summer					*Winter*				
Month of lambing	*Weaning wt.*		*Yearling wt.*		*Month of lambing*	*Weaning wt.*		*Yearling wt.*	
	Number	*Avg. (kg.)*	*Number*	*Avg. (kg.)*		*Number*	*Avg. (kg.)*	*Number*	*Avg. (kg.)*
March	90	19·3	74	31·6	Sept.	14	18·0	10	34·7
April	54	18·8	48	34·8	Oct.	63	17·0	33	37·1
May	81	19·6	60	39·0	Nov.	125	18·1	91	36·7
June	51	18·1	44	37·8	Dec.	93	18·0	80	35·3
July	5	23·8	4	40·5	Jan.	23	21·9	21	35·8
August	..	..	..	..	Feb.	5	23·0	..	..
Total	281	19·6	230	35·5	Total	323	18·9	235	36·1

provide a good milk supply for their lambs. On the other hand, ewes lambing in the winter season take some time to recover from the unfavourable summer conditions. This is reflected in the growth rates of their lambs, especially during the first 3 months.

Winter-born lambs are weaned in the middle of the berseem season, and they continue feeding on it, making fast gains, until they reach the age of about 8 months; from then on they are on summer feeding, making little further gain until 12 months of age. However, the berseem season is over even before the summer-born lambs are weaned; they are on summer feeding, making very little gain, until they are

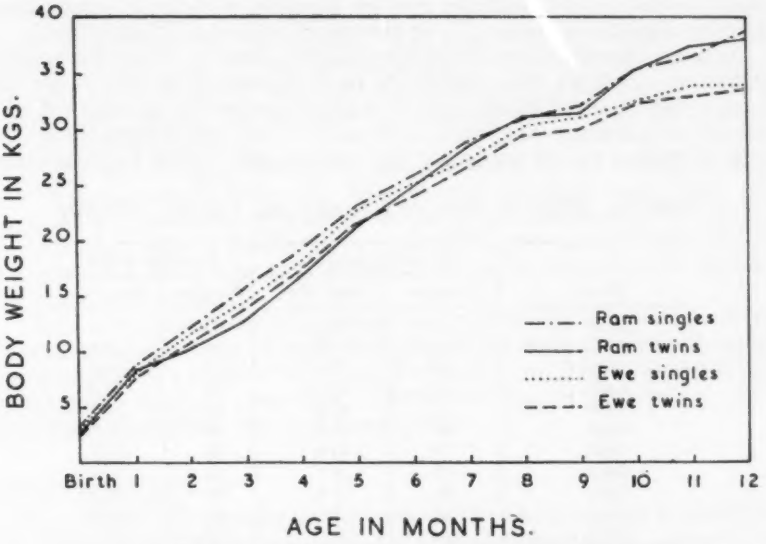

FIG. 1. Growth curves of winter-born lambs.

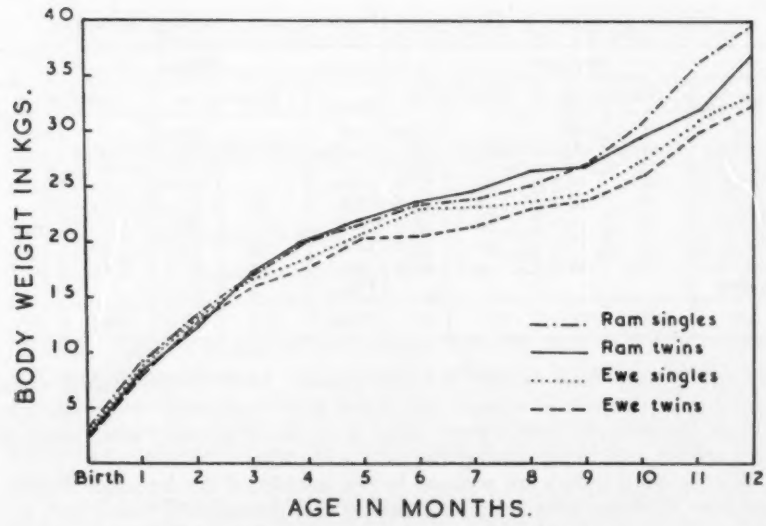

FIG. 2. Growth curves of summer-born lambs.

about 9 months of age. By that time the new berseem is available and the lambs then make fast gains once more until they reach the age of 12 months.

Asker *et al.* [4] studied the effect of season of lambing on body weight of Rahmani and Ossimi lambs at Giza. Winter-lambing was from October until March, summer-lambing from June to August. Winter-born lambs were heavier than summer-born lambs at birth and at 4 months of age. This was to be expected since summer-born lambs were born late in the season, and they and their mothers had no berseem until weaning.

It is clear that most gains were made during the winter, when lambs were on berseem, regardless of whether they were summer- or winter-born. Summer conditions need detailed study to find out the causes of the slow growth during that period. It is noteworthy that diseases and parasites are more numerous and active during the summer, and that temperature and humidity are higher.

Sex and type of birth. Table 4 presents weaning and yearling weights of the four types of birth, classified according to season of lambing. Ram lambs and single lambs were significantly heavier than ewe and

TABLE 4. *Means, Standard Deviations, and Coefficients of Variability for Weaning and Yearling Weights of Summer- and Winter-born Lambs*

Character and type of birth	Summer					Winter				
	No. of animals	d.f.[1]	Mean	S.D.	C.V. (%)	No. of animals	d.f.[1]	Mean	S.D.	C.V. (%)
Weaning weights										
Ram singles	86	75	20·1	5·3	26·4	117	106	19·1	4·5	23·7
Ram twins	51	43	20·2	6·1	30·2	55	46	16·9	3·5	20·6
Ewe singles	85	74	18·7	4·0	21·3	96	86	18·2	3·9	21·5
Ewe twins	59	49	17·7	4·2	23·6	55	44	17·5	3·9	22·1
Yearling weights										
Ram singles	62	53	39·4	6·0	15·3	79	68	38·6	6·3	16·4
Ram twins	48	42	37·0	6·7	18·0	39	29	38·1	6·6	17·4
Ewe singles	76	65	33·3	5·6	16·7	74	64	33·9	6·2	18·2
Ewe twins	44	34	32·5	5·6	17·3	43	34	33·6	5·2	15·4

[1] Within year, season, and type of birth.

twin lambs, respectively, at both ages; the interaction between sex and type of birth was not significant. Sex differences increased with age, being more pronounced at 12 months than at 4 months. The reverse was true as between singles and twins: differences decreased with age in all groups except the summer-born ram lambs. Similar results have been reported for several breeds of farm and range sheep by Donald and McLean [5], Bonsma [6], Phillips *et al.* [7, 8, 9], Hazel and Terrill [10, 11, 12], Terrill *et al.* [13, 14, 15], Morley [16]; and for the Ossimi and Rahmani sheep by Asker *et al.* [3].

Variances were calculated within year, season, and type of birth. Larger variances were associated with larger means for ram lambs as

compared with ewe lambs. Twin lambs had higher variances and coefficients of variability than singles, except in two groups. These relationships suggest that at least some of the causes of variation in body weight are acting in a multiplicative way [16]. The coefficients of variability for body weight were smaller at 12 months than at 4 months, for each type of birth. Morley [16] found that the coefficients of variability of body weight were higher at earlier ages in Australian Merino ewe and ram lambs. He also noted that this was true in weaning and yearling American range sheep. Prenatal and postnatal variations, caused by differences in uterine environment and mothering ability, could have accounted for the greater variability at weaning than at 12 months. These effects decrease as the lambs grow older.

Age of dam. Lambs from mature ewes were heavier than lambs from 2-year-old ewes, at 4 and 12 months of age (Table 5). Although the

TABLE 5. *Effect of Age of Dam on Weaning and Yearling Weights*

Age of dam, and lamb group	*Weaning*		*Yearling*	
	Number	*Avg. wt. (kg.)*	*Number*	*Avg. wt. (kg.)*
Two years old				
Ram singles	21	18·9	14	37·6
Ewe singles	11	15·7	10	33·2
Mature				
Ram singles	35	20·7	22	40·1
Ewe singles	37	18·6	29	34·2

differences were not statistically significant, they were in the same direction as those reported by Hazel and Terrill [10, 11, 12], and Terrill *et al.* [13, 14, 15] for range sheep. The differences were smaller among yearling ewes than among weanlings. Among yearling rams the differences were larger than at weaning, because rams are usually given better feed and care after weaning. Asker *et al.* [3] found that weights of Ossimi lambs at 4 and 6 months of age increased with increase of the dams' age, up to 6 years, but the differences were not significant.

Practical Considerations

Although lambs of the Egyptian breeds are born all the year round, most farmers try to have the ewes lamb in the winter season (October, November, and December). This is to make sure that ewes and their lambs will have enough feed (berseem) for about 7 months. Berseem is grown as a part of the crop rotation and also as green fodder for feeding the livestock. Any excess is turned into hay.

The present study showed that summer-born lambs excelled winter-born lambs in birth and weaning weights. After weaning, winter-born lambs grew faster than the summer-born ones, and they maintained this superiority up to 12 months of age, where the difference was 0·60 kg. The author found [17, 18] that lambing percentage was 7·4 per cent.

higher, and mortality rate (from birth to 4 months of age) was about 7 per cent. lower, among summer-born lambs. This shows that ewes lambing in the summer wean more pounds of lamb per ewe than those lambing in the winter. Even at 12 months of age the pounds of lamb per ewe are still higher for ewes lambing in the summer, in spite of the fact that winter-born lambs are somewhat heavier at that age. Summer lambing should therefore be recommended, but only to those who can afford dry-lot feeding or can grow some green fodder during the summer months. The extra expense will be covered by marketing more pounds of lamb per ewe at higher prices. Otherwise winter lambing should remain the common practice.

Growth rates decreased after weaning in all groups of lambs. Summer-born lambs showed a marked decrease until 9 months of age, then they grew relatively fast after having access to the new berseem. It does not seem economical to keep the lambs all through the summer, until the new berseem is available, so that they can feed on it until they reach market weight. It would be preferable to put the lambs, soon after weaning, on a fattening ration and have them ready for market in about 3 or 4 months. Winter-born lambs made relatively fast, also cheap, gains (feeding on berseem) until 8 months of age. From then on, growth rates dropped considerably. Lambs should not be kept in the flock beyond that age. Ram lambs can be marketed profitably at eight months, when they weigh almost 31 kg. If prices are not very encouraging (which they usually are at this time of the year) the lambs can be put on a fattening ration for a month or two until the prices are up again.

Selection of ewe and ram lambs for replacements is partly done at weaning, and the rest up to 12 months of age. The effect of type of birth and of age of dam is more pronounced at weaning than at 12 months of age. Therefore early selection should correct for these effects or it should be made within type-of-birth and age-of-dam groups. It would be more appropriate to wait until such differences are negligible whenever that is possible. This will give the lambs a greater opportunity to express their genetic constitution, since weaning weight is more or less a measure of the dams' milking ability. It will also give more emphasis on yearling weight, which is correlated with lifetime productivity of the ewes.

II. *Heritability Estimates and Correlations of Birth, Weaning, and Yearling Weights*

Body weight is the most important character affecting the selection of lambs, especially among breeds of sheep which give a small crop of wool of poor quality, typical of the Rahmani sheep. Selection is partly done at weaning and completed by 12 months of age. Sometimes birth weight is used as an early criterion for selection in cases of castration or whenever lambs are sold before weaning. Weaning weight is a measure of the inherent rate of gain and a partial measure of the milking ability of the dam. Yearling weight is a better measure of hereditary

growth rate since it is less affected by the maternal environment. Knowledge of the relationship among birth, weaning, and yearling weights is therefore important in measuring the breeding values necessary for efficient selection. Also heritability estimates of these traits are needed for accurate and efficient breeding systems.

The present study was undertaken to estimate the phenotypic relationships among birth, weaning, and yearling weights of Rahmani lambs and to estimate the heritability of body weight at the three different ages.

Data and Methods

The lambs were born and raised on the Experimental Farm of the College of Agriculture, Alexandria University, during the period 1943 to 1956. Lambs were weighed to the nearest 0·1 kg. within 24 hours of birth, and then at monthly intervals. A detailed description of the flock and the system of management has been given elsewhere [17, 18].

Classification of the data into sire groups was available from 1952 to 1956. Before 1952 sires were not identified and usually one sire was used each season. The half-sib correlation (intra-class correlation) as suggested by Lush [19] was used in estimating the heritabilities. The standard errors were calculated according to the formula given by Hazel and Terrill [20]. Before the analysis of variance was carried out, records were adjusted for the effects of year, season, sex, and type of birth.

The phenotypic correlations were calculated within year, season, sex, and type of birth. The formula used was:

$$r_{XY} = \frac{\sum_{h,i,j,k} XY - \sum_{h,i,j} (X_{h,i,j.} \cdot Y_{h,i,j})/n_{h,i,j}}{\left(\sum_{h,i,j,k} X^2 - \sum_{h,i,j} X^2_{h,i,j.}/n_{h,i,j}\right)\left(\sum_{h,i,j,k} Y^2 - \sum_{h,i,j.} Y^2_{h,i,j.}/n_{h,i,j}\right)},$$

where $X_{h,i,j,k}$ is one measurement on the kth lamb of the jth sex and type of birth, born in the ith season in the hth year. $Y_{h,i,j,k}$ is the other measurement on the same lamb. A dot in the subscript means summation over all the observations of the class indicated by the subscript for which the dot is substituted in that particular case. Regression coefficients of late on early weights were calculated in a similar way.

Results and Discussion

Heritability estimates. Table 6 presents the analysis of variance (mean squares), variance components and heritability estimates obtained. Under random mating the sire variance (σ_s^2) is expected to contain one-fourth of the genic variance plus a small amount of the epistatic variance. The expected value of (σ_1^2), the error variance, is three-fourths of the genic variance plus the environmental variance. The heritability estimate would then be $4\sigma_s^2/(\sigma_s^2+\sigma_1^2)$.

The estimate obtained for the heritability of birth weight was 0·16, which is lower than estimates reported by other workers, ranging from 0·17 to 0·61 with most of them around 0·30 [1, 21, 22, 23, 24]. The heritability estimate of weaning weight was 0·18. Estimates reported

by other workers [1, 20, 22, 24, 25, 26, 27, 28] ranged from 0·06 to 0·36.

For yearling weights the heritability estimate was 0·19. Terrill and Hazel [29] estimated the heritability of body weight for yearling Rambouillet ewes at 0·40. Morley [16] found that the heritability of body

TABLE 6. *Analysis of Variance (mean squares), Variance Components, and Heritability Estimates*

Source of variation	*Birth weight*		*Weaning weight*		*Yearling weight*	
	d.f.	*Mean squares*	*d.f.*	*Mean squares*	*d.f.*	*Mean squares*
Total	252	0·205	254	28·03	201	54·78
Between sires	8	0·581*	9	54·30*	7	109·32*
Within sires	244	0·286	245	27·07	194	52·81
	Components of variance and heritability					
k_0	23·95		21·27		20·93	
σ_s^2	0·012		1·28		2·70	
σ_e^2	0·286		27·07		52·81	
h^2	0·16±0·12		0·18±0·12		0·19±0·16	

* Significant at P = 0·05. σ_s^2 = sire variance. σ_e^2 = error variance.

weight at 10 months of age was 0·36 for Australian Merino lambs. Kyle and Terrill [28], working with Rambouillet, Targhee, and Columbia sheep born in 1951, reported estimates of heritability of yearling body weight of 0·21 and 0·40 for rams and ewes respectively.

The heritability estimates obtained in the present study were lower than most of those reported by other workers. This could have been caused by the small number of sires used (Table 6). Also, there were several unknown factors for which the data could not be adjusted and

TABLE 7. *Phenotypic Correlations and Regressions*

Lamb weights	*No. of lambs*	(*r*)	(*b*) *of late on early weights*
Birth and weaning weight	381	0·212±0·053	1·43±0·116
Birth and yearling weight	269	0·205±0·064	2·16±0·709
Weaning and yearling weight	398	0·315±0·050	0·45±0·075

which were probably largely responsible for the low heritability estimates. This is evident from the relatively high coefficients of variability obtained: 17·4, 27·4, and 18·6 per cent. for birth, weaning, and yearling weights respectively. The estimates reported here should, therefore, be treated with some reserve until more data become available.

Hazel and Terrill [20] suggested that the heritability of body weight increases from weaning to yearling age. This was true of the results obtained in the present study, although the increase was only slight.

Phenotypic correlations and regressions. Table 7 presents the phenotypic correlations and regressions obtained among birth, weaning, and yearling weights. The correlation between birth and weaning weight was 0·212. Bonsma [6] found that the correlation between birth weight and weight at 12 weeks of age was 0·41 in Merino and crossbred lambs.

Glembekii and Bogoljubova [30] estimated the correlation between birth and 4- to 6-month weights at 0·25–0·33 in Précoce, and Précoce × fat-tailed sheep. In the Ossimi sheep of Egypt, Ragab *et al.* [1] obtained a correlation of 0·59 between birth and weaning weight.

The correlation between birth and yearling weight in this study was 0·205. Glembekii and Bogoljubova [30] found 0·26–0·29 for the correlation between birth and 12- to 14-month weights. Ragab *et al.* [1] reported a correlation of 0·48 between birth and marketing weight (6 months of age).

The correlation between weaning and yearling weight in this study was 0·315. Morley [16], Terrill *et al.* [31], and Kyle and Terrill [28]

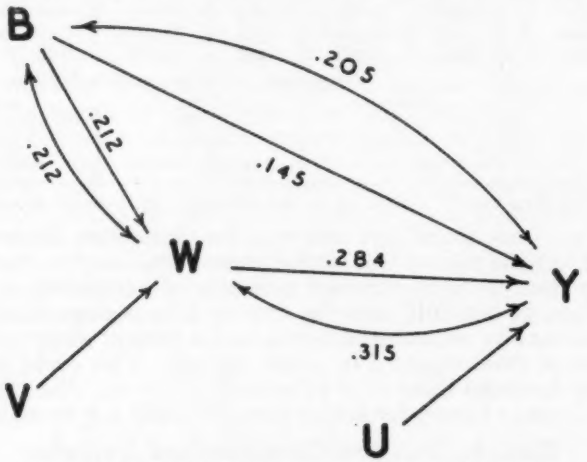

FIG. 3. Path coefficient diagram to illustrate the relation between birth (B), weaning (W), and yearling (Y) weights. The straight lines represent path coefficients and the curved lines represent correlation coefficients. The letters V and U represent unanalysed cause of variation.

reported estimates ranging from 0·50 to 0·77 for this correlation. Ragab *et al.* [1] reported a value of 0·86 for the correlation between weaning and marketing weight.

The correlations obtained in the present study were lower than those reported by other workers. Nevertheless, they all agree that the highest correlation was between weaning and yearling weight and the lowest between birth and yearling weight.

In order to evaluate the relative importance of birth and weaning weights as causes of variation in yearling weight, a path coefficient diagram (Fig. 3) was drawn. The different paths were calculated, using the correlations of the present study. The path from B to Y = 0·145, and from W to Y = 0·284, indicating that weaning weight is twice as important as birth weight in determining yearling weight. The formula for complete determination showed that about 8·1 and 2·1 per cent. of the

variability in yearling weights can be assigned to the direct influence of weaning and birth weight respectively. The joint effect was responsible for 1·8 per cent. and the rest of the variability (88·0 per cent. was associated with other factors.

The low heritability estimate of birth weight and its weak association with weights at later ages, especially yearling weight, suggests that less attention be given to it in selection programmes.

The extent to which genetic factors are responsible for the association between body weights at the different ages will affect the accuracy of the selection. Unfortunately the data were not comprehensive enough to allow for estimating these genetic correlations. They are expected to be higher than the phenotypic ones, on the basis of results presented by Hazel *et al.* [32] for growth rates in pigs and by Ragab *et al.* [1] for weights of Ossimi lambs. Hazel *et al.* concluded that heredity exerted a less important but more constant influence upon growth over the entire period (from birth to 168 days) than did environment.

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FIELD EXPERIMENTS WITH TRACE ELEMENTS ON ANNUAL FOOD CROPS IN GHANA

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Summary

Small-scale and factorial field trials have been conducted at ten agricultural stations in Ghana to investigate the responses of annual food crops to manganese, boron, copper, magnesium, iron, zinc, and molybdenum. The only favourable response was a small one to molybdenum by groundnuts, and it is concluded that, with this possible exception, deficiencies of the above trace elements are probably not important in the country's food farms.

BEFORE 1955 there had been no experiments in Ghana on the effects of trace-element applications on annual crops, although Greenwood and others [1] had studied zinc and iron deficiencies in cacao and Leather [2] has reported iron deficiencies in coffee seedlings in government nurseries. However, following the publication of work in Gambia [3], a programme of field trials was started in that year and continued with modifications in 1956 and 1957.

Experiments

In 1955 half-replicated 2^6 factorial trials were started at ten stations which cover the main agricultural regions of the country, namely at Babile, Tono, and Manga on gritty granitic soils in the densely farmed areas of the far north; at Damongo, Nyankpala, and Ejura on the medium sandy soils of Voltaian sandstones, which like the far northern stations are in the Guinea savannah woodland zone; at Wenchi and Mampong which are also over Voltaian sandstones but are near the diffuse boundary between savannah woodland to the north and semi-deciduous forest to the south, Mampong being usually classed as forest and Wenchi station as savannah; at Kwadaso on granite soils in the forest zone; and at Pokoase which is also on granite but lies just outside the southern fringe of forest in the relatively dry zone of coastal scrub and grassland.

Each half-replicated 2^6 trial was of standard design consisting of two blocks of sixteen plots. The plot size varied from $\frac{1}{70}$ to $\frac{1}{60}$ acre. To ensure that there was no severe major element deficiency, each trial received an overall NPK dressing broadcast at the start of the year, consisting of approximately 2 cwt. ammonium sulphate, 1 cwt. 'triple' superphosphate, and $\frac{1}{2}$ cwt. muriate of potash. The factorial treatments were as follows, rates referring to total quantities applied:

B = Borax at 14 lb. $Na_2B_4O_7 . 10H_2O$ per acre, applied as a 0·25 per cent. solution in water to the soil around the base of the plant 3 weeks after germination and on two successive occasions at 10-day intervals.

[Empire Journ. of Exper. Agric., Vol. 27, No. 108, 1959.]

A = Manganese sulphate at 18 lb. $MnSO_4 . 4H_2O$ per acre applied by watering-can and rose as a 0·2 per cent. solution containing approximately 0·05 per cent. Teepol wetting agent, at the same times as the borax applications.
C = Copper sulphate at 18 lb. $CuSO_4 . 5H_2O$ per acre applied as for A.
F = Ferrous sulphate at 18 lb. $FeSO_4 . 7H_2O$ per acre applied as for A.
Z = Zinc sulphate at 18 lb. $ZnSO_4 . 7H_2O$ per acre applied as for A.
E = Magnesium sulphate at 100 lb. $MgSO_4 . 7H_2O$ per acre, 65 lb. being broadcast before planting and 35 lb. being watered on the leaves as a 0·4 per cent. solution at the same times as the other treatments.

To prevent the application of one chemical washing off the deposits of others, all the salts (except borax) to be applied to each plot were dissolved in the same solution; the plot with treatment ABCEFZ therefore received a solution with total salt concentration corresponding to 1·2 per cent. of salts in the forms applied. Second-season crops in the two peak rainfall areas of Ashanti and the south received the solution treatments but broadcast dressings of magnesium sulphate and NPK were not repeated. Sites were chosen on unmanured and frequently cropped land and local seed was used in case imported seed carried traces of micro-nutrients deficient in the area of the trial.

In the same year each of the agricultural stations with a half-replicated 2^6 trial also had small eight-plot experiments to observe the effects of mixtures of borax+zinc sulphate, copper sulphate+manganese sulphate and ferrous sulphate+magnesium sulphate on tomatoes and cauliflower. These vegetables were chosen as they are useful indicators of trace element deficiencies and had been successfully grown on some agricultural stations. The plot size was 12×12 feet and the experiments were sited on previously cropped unmanured land. A general NPK dressing was applied and trace-element rates were the same as described above.

In 1956 the half-replicated 2^6 trials were continued on the same sites with modifications. No further NPK dressing was applied; rates of borax, manganese sulphate, and zinc sulphate were doubled in case the 1955 rate was too low; borax was applied to the leaves instead of to the soil; Teepol was added to the first two solution applications only and its concentration doubled; knapsack sprayers were used instead of watering-cans; the copper was applied separately as Bordeaux mixture a few days before the other elements, in order to reduce the scorching which occurred the previous year on 'C' plots.

The vegetable trials were discontinued in 1956 and four-plot trials, twice replicated, were laid down on each of the crops in the normal rotations of the ten stations to see if there were any response to molybdenum, the remaining untested element. Plot size was $\frac{1}{70}$ to $\frac{1}{50}$ acre and plot treatments were: (i) no treatment, (ii) complete NPKMg dressing+sprays of all trace elements except molybdenum, (iii) spray with 0·055 per cent. solution of sodium molybdate three times to give a total application of $2\frac{1}{2}$ lb. sodium molybdate per acre, (iv) complete NPKMg dressing+sprays of all trace elements including molybdenum.

In 1957 it was learnt that the rates of trace elements recommended by

Webb for soil application in Gambia were very low and that higher dressings were claimed to have toxic effects, so a new series of four-plot trials was designed to test these low rates on each crop in the normal rotation of 8 agricultural stations. Two of the plots received a dressing per acre of approximately 2 cwt. ammonium sulphate, 1¼ cwt. 'triple' superphosphate, ½ cwt. muriate of potash, and ½ cwt. magnesium sulphate, whilst the other two plots had 1¾ lb. per acre of a trace-element mixture broadcast in addition to the NPKMg fertilizers. The composition of the trace-element mixture was as follows:

$MnSO_4 . 4H_2O$	39·2	per cent.	by	weight
$CuSO_4 . 5H_2O$	4·4	,,	,,	,,
$ZnSO_4 . 7H_2O$	5·1	,,	,,	,,
$Na_2B_4O_7 . 10H_2O$	50·5	,,	,,	,,
$Na_2MoO_4 . 2H_2O$	0·9	,,	,,	,,

Some of the previous year's half-replicated 2^6 trials were continued in 1957 with no further applications to see whether any of the trace element treatments had residual effects.

Results

Vegetable trials

These suffered badly from pests and diseases. This was partly because the small plots were sited well away from station vegetable gardens (since these are always manured) and on poor land; and partly because cauliflowers often do not grow well in the Ghana climate; on many sites eelworm attacked the tomatoes. Some of the trials had measurable yields and, when points were allocated to the treatments in each trial at the rates of 4, 3, 2, 1, for a first, second, third, or fourth place, then the total score sheet showed on average no evidence that any trace element had significantly benefited the plants; furthermore, no treatment was outstanding at any one station and none of the vegetables showed trace-element deficiency symptoms.

Half-replicated 2^6 Trials

In the first year copper sulphate scorched the leaves of most crops and in six cases significantly harmed later growth; ferrous sulphate also seemed to cause a little scorching, especially if used in combination with the copper. Yield responses were generally small except for the negative responses to copper sulphate. Two changes were therefore made to the treatments in the second year; the copper was applied separately as a dilute Bordeaux mixture and the spray rates of magnesium, manganese, boron, and zinc were doubled. Although this resulted in reducing scorch by copper, yield responses were not improved and the higher rate of zinc sulphate significantly damaged the foliage of groundnuts in the Northern Region.

In Table 1 the average yield results over both years are given for each station. The main effects were statistically significant as follows: manganese once negative, boron nowhere significant, copper three times

TABLE 1. *Mean Yields and Trace-element Responses in lb./acre for Half-replicated 2^6 Factorial Trials*

A = Manganese sulphate C = Copper sulphate F = Ferrous sulphate
B = Borax E = Magnesium sulphate Z = Zinc sulphate

STATION	*Pokoase*	*Kwadaso*		*Mampong*		*Ejura*		*Wenchi*		*Nyankpala*		*Damongo*		*Babile*		*Tono*		*Manga*	
CROP	*Maize*	*Maize*	*Groundnuts*	*Maize*	*Groundnuts*	*Maize*	*Groundnuts*	*Maize*	*Groundnuts*	*Maize and Guineacorn*	*Groundnuts*	*Maize and Guineacorn*	*Groundnuts*	*Maize and Guineacorn*	*Groundnuts*	*Early Millet and Guineacorn*	*Groundnuts*	*Early Millet and Guineacorn*	*Groundnuts*
No. of trial seasons	2	2	2	2	2	2	2	1	2	1	1	1	1	1	1	1	1	1	1
Mean yield	1,012	1,202	95	1,409	354	1,319	824	1,121	164	1,592	451	2,288	1,493	1,650	565	1,086	1,369	1,070	785
Responses to treatments:																			
A	−79	71	−54*	−188	−46	121	31	183	7	130	−57	10	31	151	−59	−88	−68	−40	−50
B	−54	10	−11	−107	25	113	62	−102	−12	65	−41	−132	−71	201	109	−116	−27	20	50
C	−197*	10	−8	−56	25	−381†	46	20	48	−455†	−57	−112	31	−167	−25	143	0	0	−10
E	−54	62	−4	158	−25	−106	0	163	−20	98	73	71	31	67	−42	−34	0	0	−150†
F	−46	71	30	127	5	106	0	82	−13	17	−57	30	−31	−33	−42	48	−54	120	50
Z	−46	−163*	11	239	25	20	−15	−102	30	−179	−106*	−10	−173	−51	−494†	7	14	−60	−310†
AB	−130	142	2	86	5	51	−23	0	−1	131	41	71	31	33	59	238*	0	0	30
AC	−4	20	2	−147	−35	97	70	−122	−9	−65	−73	−235	51	0	25	7	27	−60	50
AE	−96	91	−2	107	−5	66	−39	−143	−3	65	−73	31	−31	−67	8	−62	0	−60	110†
AF	12	61	1	137	−15	−35	39	143	−4	−49	−8	−91	−10	−67	−25	21	−82	−60	30
AZ	−54	−71	0	5	−15	19	−70	122	17	−81	−24	−92	10	84	25	116	−41	0	−10
BC	88	−20	15	35	−5	43	−23	−82	−62*	−33	−57	31	−10	−117	−75	−75	14	−80	30
BE	−4	92	2	25	25	89	23	102	−52	−65	−57	−194	−10	184	42	−61	68	120	−30
BF	104	81	−25	35	15	−74	−8	−20	37	17	8	−30	10	−17	−25	102	41	−40	10
BZ	−79	−10	−22	127	15	74	−55	0	−1	16	−41	10	−10	0	25	−102	−27	60	50
CE	54	132	21	−76	35	−97	7	−143	1	0	−41	−133	10	51	8	−88	−41	100	−50
CF	146	−20	−35	147	−5	3	−16	−20	−17	49	24	30	31	−17	−92	−34	−41	100	−10
CZ	−21	−71	3	−147	−5	11	39	204	−9	−212*	8	153	−31	67	159	129	82	−40	−130†
EF	121	−30	−11	−209	−56*	191	−8	0	19	−16	24	−234	−10	117	126	−34	−14	−20	−10
EZ	54	−61	−20	5	−15	27	39	143	24	−114	8	51	92	−34	142	−102	82	40	50
FZ	−105	30	−14	117	36	−105	8	−61	−9	−97	8	−71	−10	0	−109	88	27	−80	−110†
5% significance level (P = 0·05)	182	145	42	241	49	184	85	270	62	193	80	402	148	209	204	166	101	167	74

* Significant at P = 0·05. † Significant at P = 0·01.

negative, magnesium once negative, iron nowhere significant, zinc four times negative. The only significant interactions were manganese × boron and manganese × magnesium, each once positive; boron × copper, iron × magnesium, and iron × zinc, each once negative; and copper × zinc twice negative. It appears, therefore, that no trace element was appreciably beneficial; on the contrary, the biggest effects were reductions in yield brought about by the copper and zinc treatments. These conclusions from the yield figures are supported by the absence of deficiency symptoms or markedly favourable growth responses in any of the trials.

Molybdenum Trials

Responses to sodium molybdate at each station are shown in Table 2, from which it can be seen that applications of sodium molybdate solution to the foliage usually increased the yields of groundnuts and decreased the yields of the non-legumes. Averaged over all trials both these effects were just significant at the 5 per cent. level; the cereal figures were extremely variable, giving a very high standard error.

Trials with Trace-element Mixture recommended for Gambia, and the Residual Effects of the Half-replicated 2^6 Factorial Trials

Yield responses to the mixture of trace elements recommended by Webb are shown by stations in Table 3. They were not large and were not statistically significant.

Residual effects of the half-replicate 2^6 trials are given in Table 4. Only two main effects were larger than the 5 per cent. significance level, namely, manganese on maize at Wenchi and zinc on guineacorn at Babile; the first was positive (i.e. plots which had manganese in previous years yielded high) and the second was negative. Four interactions are marked as significant in the table, but they were so on only one of two mixed crops and fall below the significance level when the combined response of both crops is considered.

Both these series of trials therefore agree in indicating that low levels of trace-element applications were ineffective in increasing crop yields.

Discussion and Conclusions

It may be argued that appreciable responses to trace elements have not been found because there were sufficient micronutrient impurities in the overall NPK dressings to remedy any deficiencies. It is, however, unlikely that these moderate rates of ammonium sulphate, 'triple' superphosphate, and muriate of potash would have supplied enough of any micronutrient (excepting perhaps molybdenum) completely to hide a serious deficiency. Furthermore, experiments in Ghana with different rates and types of NPK fertilizers support the view that where responses are obtained they are at least mainly due to the major elements supplied, so that it is unlikely that trace-element impurities play more than a very minor role.

TABLE 2. *Crop Responses to Applications of Sodium Molybdate both with and without the Addition of Other Nutrients*

(Responses expressed as percentages of means)

		Kwadaso	*Mampong*	*Ejura*	*Wenchi*	*Nyankpala*	*Damongo*	*Babile*	*Tono*	*Manga*	*Average of all sites*
Cereal grain	Molybdenum with other nutrients	−56	−13	−52	−37	−22	−63	−60	..	..	−49
	Molybdenum without other nutrients	−119	−19	−46	−92	−89	19	−7	..	..	(5% significance
	No. of sites	4	2	4	2	2	3	4	..	..	level = 46)
Groundnut kernels	Molybdenum with other nutrients	17	17	−12	−17	47	22	..	26	0	+12
	Molybdenum without other nutrients	0	17	7	−17	47	38	..	7	0	(5% significance
	No. of sites	2	2	4	2	2	3	..	2	2	level = 11)
Yam tubers	Molybdenum with other nutrients	..	..	..	..	−12	..	..	..	..	
	Molybdenum without other nutrients	..	..	..	..	12	..	..	..	..	
	No. of sites	..	..	..	..	2	..	..	..	..	

TABLE 3. *Crop Responses to the Trace-element Mixture*

(Responses expressed as percentages of means)

		Kwadaso	*Mampong*	*Wenchi*	*Nyankpala*	*Babile*	*Tono*	*Manga*	*Average of all sites*
Cereal grain (Excl. rice)	Response to mixture	7	10	−10	8	−14	3	−26	−1 (5% sig. level = 6)
	No. of sites	4	4	4	2	4	4	4	
Groundnut kernels	Response to mixture	0	−8	−9	9	30	27	0	+6 (5% sig. level −23)
	No. of sites	2	4	4	2	2	2	2	
Swamp rice	Response to mixture	..	..	..	−3	..	..	..	..
	No. of sites	..	..	..	2	..	..	..	..

TABLE 4. *Residual Responses and Mean Yields in lb./acre of Grain or Kernels during Year following Treatment Applications in Half-replicated 2^6 Factorial Trials*

(Treatment symbols are as for Table 1)

STATION	*Kwadaso*	*Wenchi*	*Nyankpala*	*Babile*		*Manga*	
CROP	*Maize*	*Maize*	*Groundnuts*	*Maize*	*Guinea-corn*	*Early Millet*	*Guinea-corn*
Treatment							
Mean yield	1,145	1,285	300	945	647	740	890
A	70	210*	40	−8	34	20	−100
B	10	−70	−24	−42	151	−20	100
C	30	−170	8	−92	168	−120	−20
E	−90	−10	24	142	168	40	120
F	50	110	8	8	34	20	60
Z	150	−50	−8	−126	−252*	60	0
AB	−10	−70	24	42	−202	−40	−60
AC	10	−130	−8	227*	−50	140	20
AE	50	30	40	59	−17	−180*	40
AF	−10	70	24	25	151	−80	−60
AZ	−150	−130	40	25	34	−80	40
BC	−90	70	−8	−142	−101	−20	20
BE	70	−50	8	25	−34	60	0
BF	130	−130	−8	59	−168	0	60
BZ	70	110	40	−76	118	80	40
CE	−110	−190	8	42	17	160*	−240*
CF	−90	130	−8	109	50	60	20
CZ	170	10	8	109	0	−60	0
EF	−50	−110	8	8	118	20	80
EZ	−70	50	24	−126	−101	60	60
FZ	−130	−150	−24	−126	−168	0	−40
5% significance level (P=0·05)	269	191	69	210	208	145	176

* Significant at P = 0·05.

It is therefore concluded that the trials described here indicate that in Ghana the common annual food crops do not suffer any severe trace-element deficiency when grown normally in the field. This is confirmed by the general appearance and yields of crops on farms and agricultural stations, where the soils are usually slightly or moderately acid, trace-element deficiency symptoms have rarely been noted and responses to NPK fertilizers are often considerable [4]. With the development of more settled and intensive farming systems in Ghana, the introduction of more demanding varieties of crops, and the exploitation of new areas, commercial fertilizers may have to be supplemented with micronutrients to get optimum yields; but at present it seems that attention should be mainly confined to the macronutrients nitrogen, phosphorus, potassium, sulphur, and perhaps calcium, with subsidiary experiments to confirm the small favourable responses of groundnuts to molybdenum.

Acknowledgements. Mr. P. H. Nye's advice has been most valuable, especially with regard to the 2^6 trials, and Mr. Webb kindly supplied details of his own work which have been of great help. Finally, the author must acknowledge with gratitude the assistance received from senior and junior staff of the Department of Agriculture, especially the Chemistry Division, of whom Mr. R. K. Djokoto must be particularly mentioned.

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THE POTENTIAL OF LUPINS AS CROP AND FORAGE PLANTS IN WESTERN AUSTRALIA

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WITH PLATE 10

Summary

Trials in Western Australia showed that *Lupinus digitatus*, *L. angustifolius*, *L. luteus*, and *L. albus* are all capable of good yields under suitable conditions. *L. luteus* grew best on light soils and *L. albus* on heavier soils, while *L. digitatus* and *L. angustifolius* grew well over a wide range of soil types. The indications were that all four would succeed best in districts with an annual rainfall of 20 inches or more.

Comparatively little within-species variation in vigour of growth was apparent. New and introduced varieties generally compared favourably with existing commercial varieties. No differences in growth could be detected between bitter and alkaloid-free varieties, except that the latter, being palatable, were more susceptible to damage by grazing, and in the case of *L. luteus* to attack by red-legged earth mites (*Halotydeus destructor*).

The most promising types for commercial use in Western Australia are the alkaloid-free, soft-seeded, non-shedding varieties of *L. luteus* and *L. albus*. These could be harvested as a grain crop, and the grain used as a protein concentrate. It should also be possible to grow *L. albus*, *L. angustifolius* and *L. luteus* in other parts of southern Australia, although nodulation problems exist. If good nodulation could be assured, the way would be open for lupins to become an important and valuable crop.

ALTHOUGH lupins have been present in Western Australia for nearly a century, both cultivated and naturalized, they have received comparatively little scientific attention.

In a few districts the 'West Australian blue lupin' (*Lupinus digitatus* Forsk.) has been grown quite extensively during the last 40 or 50 years on sandy soils, for soil improvement and as summer feed for sheep. Since about 1930 there have also been plantings of the 'New Zealand blue lupin' (*L. angustifolius*). At first, this variety was used exclusively as a green manure crop, but during the last few years there have been increasing areas grown for sheep feed, mainly in districts with an annual rainfall of 25 inches or more.

The seeds of lupins provide a protein-rich (30–35 per cent. protein) supplement to the dry annual grass pasture. Grazing of the fallen seeds and leaves takes place from the time the plants mature (November) until the first autumn rains in April or May. Ample seed is usually trodden into the ground to provide for natural regeneration.

Small areas of the 'yellow lupin' (*L. luteus*) have been grown occasionally during the last 30 years for green manure, and *L. albus* also is very occasionally planted. Several other species are grown purely for ornamental purposes. Altogether at least nine species are present in Western Australia. Their taxonomic identities are discussed by Gladstones [1].

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The first reported experimental work with lupins in Western Australia, described by Thomas [2], was a field trial with the West Australian blue lupin. Thomas and Shier [3] published observations on fifty strains of various lupin species obtained from Germany. None of the new strains showed much promise, and there are no published reports of further work with them. In 1929 the West Australian Department of Agriculture laid down long-term rotational trials, including lupins at the Chapman and Wongan Hills Research Stations. A further rotational grazing trial with a treatment including the West Australian blue lupin was laid down on light land at the Wongan Hills Research Station in 1946. The results are discussed by Drover [4].

Interest in lupins waned after the advent of subterranean clover in the wheat-belt, although some work continued on a small scale. Observations on lupin varieties are reported by Ryan [5], and were continued for a few years by Rossiter (unpublished). Subsequently, an investigation was carried out by Norris [6] on a virus disease of lupins which was prevalent in districts within 50 miles of Perth. Later, lupins were included in a study by Bailey [7] of possible alternatives to field peas in the 16–25-inch rainfall belt, but were not considered promising for this purpose. Similarly, they compared very poorly with *Pisum*, *Lathyrus*, and *Vicia* species and varieties in trials on the Coonalpyn Downs in South Australia [8].

Present Trials

The present investigation was started because the practical success of lupins in limited areas and their obvious adaptation to the sandy soils which characterize much of the agricultural region of south-western Australia appeared to make them worthy of closer scientific attention.

It soon became apparent from the literature that a number of types of lupins were cultivated overseas which were not known in Australia, and that some of them could be valuable under local conditions. As new introductions were obtained, they were first compared visually in rows. The most promising of these were then compared with existing varieties in small-scale yield trials. Ten yield trials were carried out at various sites in 1955, 1956, and 1957. Throughout the trials the commercial-type West Australian blue lupin, the commercial-type New Zealand blue lupin, and the bitter yellow lupin were grown as standard varieties. In addition, a wider range of varieties not included in the trials were grown at each site for visual comparison. Only the more important features of the results are dealt with here.

The four main species examined, *L. digitatus*, *L. angustifolius*, *L. luteus*, and *L. albus*, all showed themselves capable of giving high yields under suitable soil and rainfall conditions. However, the optimum conditions for the different species varied. The trials showed that all species need more rainfall than cereals for their best development and suggested that they would not be satisfactory crops for parts of the State with an annual rainfall of less than 16–18 inches. Yields are highest when germination occurs early (April). Where lupins are used for summer grazing and seed is shed naturally, they germinate with the first

rains and make an earlier start in autumn. Under these conditions they can often seed satisfactorily in drier districts.

Where the April–October rainfall was 14 inches or more, seed yields obtained in the trials ranged approximately from 10 to 45 bushels per acre (assuming 1 bushel = 60 lb.), and yields of dry matter at about the end of flowering ranged from 30 to 75 cwt. per acre. This included several cases where particular species were grown on unsuitable soils. In general, growth in the higher-yielding trials was similar to that of average or better commercial crops in the same districts.

On this basis it is estimated that in districts with an annual rainfall of 20 inches or more, and with adequate soil preparation and successful nodulation, seed yields of 20–40 bushels per acre, or dry-matter yields of 2–4 tons per acre, at the end of flowering, should be obtainable in normal seasons. *L. albus* and *L. angustifolius* may yield as high as 50 bushels per acre under particularly good soil and seasonal conditions (early opening rains and good spring rains). The potential seed yield of *L. luteus* is probably a little lower than that of the other species, but the seed-protein content is higher, and strains exist which are completely non-shedding.

No other species showed any promise of being useful commercially. *L. pilosus* (which is similar to *L. digitatus*) and *L. mutabilis* are both large-seeded, but appear to be too low-yielding under Western Australian conditions, though *L. mutabilis* has received some attention in Europe on account of the rather high oil content of its seeds [9]. *L. pubescens* and *L. hartwegii* are both small-seeded, and useful only as ornamentals.

In the material examined, within-species differences in vigour of growth did not appear great. Observation suggested that such differences as were apparent could be attributed largely to differences in seed size.

The four species showing promise are examined individually below.

L. digitatus

This species gave good yields in nearly all trials and grew equally well on loamy soils and deep sands, but it appears to persist best from year to year on the lighter soil types. Flowering at Perth is normally during the latter half of August, and it matures during the first half of November.

The main disadvantages of the species are: susceptibility to virus diseases; susceptibility to frost (it was the only species to suffer appreciable frost damage at any of the sites in 1957); the shedding of its seeds immediately they are ripe; and extreme hard-seededness. The last characteristic is probably an advantage in a long-term ley but creates difficulties in the initial establishment, although a technique has now been found by which it can be overcome [10]. Evidence to date suggests that the species is completely self-pollinated.

L. luteus

In the present trials *L. luteus* proved comparable in dry-matter yields with the other species. On the other hand, seed production, where measured, was seldom equal to that of *L. digitatus* or *L. angustifolius*, but in one sense its higher seed-protein content compensates for this (about

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On this basis it is estimated that in districts with an annual rainfall of 20 inches or more, and with adequate soil preparation and successful nodulation, seed yields of 20–40 bushels per acre, or dry-matter yields of 2–4 tons per acre, at the end of flowering, should be obtainable in normal seasons. *L. albus* and *L. angustifolius* may yield as high as 50 bushels per acre under particularly good soil and seasonal conditions (early opening rains and good spring rains). The potential seed yield of *L. luteus* is probably a little lower than that of the other species, but the seed-protein content is higher, and strains exist which are completely non-shedding.

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In the present trials *L. luteus* proved comparable in dry-matter yields with the other species. On the other hand, seed production, where measured, was seldom equal to that of *L. digitatus* or *L. angustifolius*, but in one sense its higher seed-protein content compensates for this (about

40 per cent. against 30–35 per cent. for the other two). Total seed-protein yields were similar for the three species.

The trials in which *L. luteus* did best in comparison with other species were those on the poorest soils. This species seems well adapted to sandy and gravelly soils, a finding consistent with European experience [11]. Growth during the winter tended to be rather slow, but was very rapid in spring, and it is possible that *L. luteus* may be more dependent on spring rains than the other species.

The main interest in *L. luteus* lies in the alkaloid-free varieties, and there was no evidence that these varieties were any less vigorous than the bitter ones. Alkaloid-free varieties gave lower yields in some of the trials, but this was due primarily to more serious damage by red-legged earth mites (*Halotydeus destructor*). Where there was little mite damage, they were quite as vigorous as the bitter varieties.

The most promising alkaloid-free varieties were the German-bred Weiko II and Weiko III. In addition to being alkaloid-free, these differ from the common bitter type in being non-shedding, soft-seeded, and white seeded. Weiko III, which is a comparatively new variety, also carries a gene for 'rapid early growth' (*frohwuchsigkeit*), which results in a more erect growth habit and slightly earlier maturity than in the older varieties. The start of rapid growth in spring is also earlier. German breeding work with *L. luteus* is described by Hackbarth [12] and Hackbarth and Troll [13].

The non-shedding character held good under local conditions, and the plants were found to hold their seeds for at least 2 months after maturity unless disturbed. Similarly, the soft-seeded varieties gave immediate and 100 per cent. germination, except where there had been physical damage to the seeds in threshing. Little or no bitterness was detectable in the seeds of pure alkaloid-free varieties.

Apart from having earlier maturity, Weiko III appeared appreciably less susceptible to red-legged earth mites than the other alkaloid-free varieties, although it is still more susceptible than the bitter varieties. The reason is probably that the extremely susceptible cotyledons and growing points of the seedlings are lifted clear of ground level from the beginning, whereas in strains with the normal growth habit they remain close to the ground for 2 to 3 months (Fig. 1, Pl. 10). Altogether, Weiko III seems to be the best of the available alkaloid-free varieties of *L. luteus*, and pure seed is now being multiplied up for commercial distribution.

L. luteus is the only one of the agricultural lupin species in which a substantial amount of cross-pollination has been shown to take place. Various workers in Europe and Florida estimate it to be between 20 and 40 per cent. Observation suggests that the figure under local conditions may be even higher.

L. angustifolius

As with *L. digitatus*, *L. angustifolius* showed no marked reaction to soil type in yield trials, but practical experience has generally been that the best results are obtained on slightly heavier soils than with *L. digitatus*. In Germany it will not flourish on such poor soils as *L. luteus* [11]

However, there are probably few soils in the agricultural districts of Western Australia on which it would not grow satisfactorily.

No yield differences have been apparent between alkaloid-free and bitter varieties. The alkaloid-free variety which was released some years ago in New Zealand [14] is precluded from further consideration because of its extreme hard-seededness. On the other hand, the variety Borre, which was bred in Sweden [15], is fully soft-seeded and differs little from the commercial bitter variety, except that it is alkaloid-free. Pure seed is being multiplied for commercial distribution. The variety has shown considerable promise in New Zealand, and has already been released there [16].

L. angustifolius has generally been found to be exclusively self-pollinating [13, 17, 18]. Under Western Australian conditions, however, a low but significant amount of cross-pollination has been shown to occur [19].

No non-shedding varieties of *L. angustifolius* have yet been found, but shedding takes place less readily than in *L. digitatus* or the shedding varieties of *L. luteus*. This allows a reasonable proportion of the seed to be harvested. The time of maturity is similar to that of *L. digitatus*, or sometimes slightly later.

L. albus

This species must be considered separately from the others, because it is the only one which needs a reasonably fertile soil. German experience is that it is capable of very high yields on suitable soils [20], and this has been borne out in the present trials. At Chapman in a favourable season, on a red-brown sandy loam, the late-maturing bitter variety N. 2085 yielded 47 bushels per acre, which was the highest yield recorded in any trial. Early-maturing bitter varieties grown in rows adjacent also grew very well. In other trials in the same year, on sandy soils, N. 2085 was distinctly unthrifty and yielded poorly.

Because no alkaloid-free variety was available at the time, *L. albus* was not included in yield trials in 1956 and 1957, but an alkaloid-free, fairly early-maturing variety has now been obtained, and trials have been sown in 1958 at Chapman and Esperance. Other observations suggest that late-maturing varieties of *L. albus* may be capable of high yields on heavier soils in high rainfall areas of the south-west of Western Australia.

L. albus is naturally soft-seeded and non-shedding, so the alkaloid-free varieties are comparable with the Weiko II and Weiko III varieties of *L. luteus* as potential grain legumes. According to Hackbarth and Troll [13] their seed-alkaloid content is only about 0·02 per cent. This is lower than in the 'alkaloid-free' varieties of *L. luteus* and *L. angustifolius*, which are recorded as having about 0·05 per cent.

Bitter varieties with a wide range of maturities are on hand, and present the possibility of breeding types suitable for both higher and lower rainfall areas. The main disadvantages of the species are the long period between flowering and maturity (which makes it very susceptible to climbing cutworm attack) and susceptibility to the fungal 'leaf spot' disease *Pleiochaeta setosa*.

Potential Uses of Lupins

There are three uses to which the lupin varieties now on hand could be put. These are: (1) for summer grazing when mature, as at present practised; (2) as legumes harvested for grain; and (3) as a forage crop for hay, silage, or green grazing.

Summer Grazing

Both *L. digitatus* and the bitter variety of *L. angustifolius* have proved suitable for this purpose on light soils in parts of south-western Australia with an annual rainfall of 16–20 inches or more, and there is room for a considerable expansion of their use in this way. Lupin-growing in drier areas is more problematical, but there have been indications that difficulties there may be connected with establishment and management as well as with the ability of lupins to grow under those conditions, and it is possible that lupins could fill a useful place, especially on deep sandy soils not well suited to other pasture species.

Several disabilities have discouraged the growing of lupins for sheep-feed in the past. The most important are 'lupinosis', losses from climbing cutworms, and difficulties of establishment. Sheep losses through the disease lupinosis have in general not been great, although in individual cases since 1950 they have been serious. The problem is discussed by Bennetts [21], but no solution has yet been found.

Seed losses from climbing cutworm (*Heliothis punctigera*) have in the past been extremely serious, more so than has been generally realized. It is now known that they can be controlled with DDT. The problems associated with establishment are only now being recognized, and appear to be connected largely with poor and ineffective nodulation and possibly phosphate requirements. With a full understanding of these problems, it is hoped that two of the three main obstacles to lupin-growing will be removed.

The use of alkaloid-free lupins for grazing by sheep is a possibility which has not yet been tested in Australia. In contrast to the present bitter varieties, which are to a certain extent protected from grazing when green by their bitterness, it would not be possible to graze fields in which they were growing. However, although it has not been shown that any serious consequences follow the intake by sheep of the alkaloids in bitter varieties, the alkaloid-free varieties would be more palatable, and the non-shedding ones would provide good summer grazing for cattle as well as sheep, in addition to having alternative uses.

As Grain Legumes

The use of non-shedding, alkaloid-free varieties as grain legumes is by far the most interesting new possibility for southern Australia, especially those varieties which thrive on poor sandy soils.

One possible difficulty is that germination would tend to be later when sown for a crop than with natural seeding in established stands. The importance of an early start to growth in the autumn is very apparent under Western Australian conditions. This might confine the growing of

lupins as a grain crop to districts with a slightly longer growing season than for summer grazing, especially where inoculation of the seed is necessary. The results described in this paper indicate that the best yields would probably be obtained in districts with an annual rainfall exceeding 20 inches, but it is possible that economic yields might still be obtained in drier districts.

Unsatisfactory nodulation, the other main problem, has already been mentioned. To grow lupins as a crop, it is essential that good nodulation is ensured in the year of planting.

The uses to which alkaloid-free lupin grain could be put need only be mentioned briefly here. The seeds of all species have a high protein content. The percentages reported by various authors [13, 22, 23, 24] are approximately as follows (per cent. crude protein on dry-matter basis, whole seeds): *L. angustifolius* and *L. digitatus* 28–36 per cent.; *L. albus* 30–40 per cent.; and *L. luteus* 37–48 per cent. *L. albus* also contains about 10 per cent. oil, but the other species have only 5 per cent. or less [13].

The biological value of the protein is, for vegetable protein, high. German evidence is summarized by Hackbarth and Husfeld [11]. It was found there that *L. albus* and *L. luteus* were particularly satisfactory in this respect, but *L. angustifolius* somewhat less so. In Australia, Stewart, Moir, and Rogerson [25] showed that the proteins of lupin seed (*L. digitatus*) and linseed had a considerably higher biological value for wool growth in sheep than those of peas and subterranean clover. By comparing the essential amino-acid make-up with that of whole-egg protein, Holmes [26] ranked a number of vegetable proteins in the following order of decreasing biological value: lupin (*L. digitatus*), vetch, linseed, pea, subterranean clover. Being palatable, alkaloid-free lupin grain would thus be valuable in pig, poultry, and dairy rations. Quite a number of feeding trials have, in fact, already been carried out in Germany and South Africa [27, 28, 29, 30, 31, 32, 33, 34, 35, 36]. For pig- and poultry-raising, at least half to two-thirds of the meat meal or fish meal commonly used can be replaced by crushed lupin grain without loss of production or quality, but for egg production the proportion appears to be somewhat less.

Alkaloid-free Lupins for Silage, Haymaking, and Green feed

Silage. Bitter lupins have at times been used in silage-making, but various studies have shown that the alkaloids are not destroyed in the process [37, 38, 39]. Consequently, alkaloid-free varieties are much to be preferred for this purpose.

The alkaloid-free varieties are used quite widely in northern Europe for silage-making. Winkler *et al.* [40] describe comprehensive experiments in Sweden. *L. luteus* was found to be very easily ensiled, and gave silage of particularly high quality, but *L. angustifolius* was rather less suitable on account of its greater woodiness, lower palatability, and lower feed value. With *L. luteus* by far the best results, in terms of digestible nutrients per acre, were obtained when ensiling was delayed until the start of seed formation. The Swedish results parallel earlier German

experience, reviewed by Hackbarth and Husfeld [11]. They describe *L. luteus* as being easier to ensile than vetches and clover. The addition of ½ to 1 per cent. sugar, or patent additives is recommended, as is ensiling when pod formation is complete and seeds are beginning to form. More recently, alkaloid-free strains of *L. luteus* have come to be used for silage-making in South Africa. Marais [41] recommends adding 60–80 lb. of molasses per ton of green matter because of the high protein content.

No trials have yet been made in Australia with alkaloid-free lupins for silage-making, but on the basis of overseas experience it appears that *L. luteus* would be very suitable.

Haymaking. Similar considerations apply to haymaking as to silage-making. Except at early stages, *L. angustifolius* is too woody and also has the disadvantage of dropping its leaves very readily. *L. albus* would also be too woody for good hay. *L. luteus*, on the other hand, can be used up to quite an advanced stage of maturity, and does not shed its leaves readily. Marais [41] describes it as a very promising hay crop in the western Cape area of South Africa, and the same should apply under similar conditions in southern Australia.

As a variant of haymaking, there is the further possibility with non-shedding varieties of not cutting until the plants are fully mature. They could be fed as they are, or after grinding. Two South African analyses of ground alkaloid-free lupins (entire mature plants, including seeds), given by Marais [41], show 12·0 and 14·4 per cent. crude protein, and 36·4 and 30·1 per cent. crude fibre, respectively. The meal obtained in this way should be a valuable feed, and the protein content could, if desired, be raised considerably by harvesting only the tops of the plants.

Green feed. The use of alkaloid-free lupins for green feed might be indicated on very poor soils, or where it is desired to provide an alternative to grazing green clover-dominant pastures. In New Zealand, mixtures of rape and the Borre variety of *L. angustifolius* have been found very suitable for fattening lambs [42]. Grazing would not be feasible before about the end of flowering, because lupins recover poorly from cutting or grazing in the green state. Analyses in 1956 showed both *L. angustifolius* and *L. luteus* to contain 15–16 per cent. crude protein in the whole tops between full flowering and the seed-forming stage. There appeared to be little fall in crude protein content with increasing maturity, but *L. luteus* would be the most suitable species on account of its lesser tendency towards woodiness.

Discussion

Throughout the trials new and introduced varieties generally compared favourably with existing varieties, and several showed great promise. Contrary to earlier reports the yields obtained in these studies were generally good, and with more data on the suitability of particular varieties for different districts and soil types, and proper treatment, it should be possible to obtain very satisfactory yields in farm practice. In the light of newer knowledge, it seems probable that poor results in past trials were due mainly to late planting and poor nodulation. It

should also be remembered that most of the more promising varieties have only become available during the last 5–10 years.

The need for a suitable cash crop in the higher-rainfall districts of Western Australia (those with an annual rainfall of more than 20 inches) is a very real one. There are large areas of uncleared sandy and gravelly soils which could profitably be developed and used if such a crop could be found. Lupins have the important advantage of being legumes, and the Weiko III-type varieties of *L. luteus* appear particularly promising for the purpose on account of their adaptation to poor soils, their soft-seededness, their high seed-protein content, and their suitability for mechanical harvesting.

The south-western coastal plain seems particularly suitable for *L. luteus*. Winter temperatures here are mild and the rainfall high. Many of the soils dry out at the surface early in the spring, and lupins have the advantage of being deep-rooted, so that they can continue growing after shallow-rooted species have dried off. (It is notable that sandy coastal soils in the western Mediterranean area are the natural habitat of all the agricultural species of lupins, except possibly *L. albus*.) The Esperance plain may also prove well suited to *L. luteus*, on account of its long growing season.

In the eastern States the most suitable species may be *L. albus*. This species appears to tolerate cold winter conditions, and is widely grown in Italy. It is also grown as a summer crop in the Balkan States and the Ukraine. Alkaloid-free varieties may be well worth trying on the heavier soils and in the cooler parts of New South Wales and Victoria. All species could probably be grown as a summer crop in Tasmania. Autumn-sown crops of *L. angustifolius* and perhaps *L. luteus* should succeed in coastal districts of south-eastern South Australia and western Victoria provided they can be sown early enough, and in the coastal districts of New South Wales under conditions analogous to those under which these species are widely grown in the Gulf Coast States of the U.S.A. In all cases the critical requirements, apart from adequate soil preparation and fertilizer use, would be early sowing and effective inoculation.

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FIG. 1. Left, standard growth habit; right, erect growth habit of the variety Weiko III.

LARGE-SCALE TRIALS WITH INSECTICIDES AGAINST CAPSIDS ON CACAO IN GHANA

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WITH PLATE II

Summary

Capsid damage to cacao trees is described and its importance explained. The present investigation on chemical control has been made possible by the advent of suitable machines for applying insecticides. The value of spraying mature cacao with DDT and gamma-BHC miscible liquids, and dusting with BHC, for capsid control, was assessed at twenty-six sites in 1954. Spectacular results were obtained and the BHC treatments were found superior to DDT. Yields assessed in the following year showed an increase on both treated and control plots in the Eastern Region and in Ashanti. In 1955 trials were conducted to ascertain the optimum dosage of gamma-BHC miscible liquid and intervals between applications. Results were not clear-cut, but led to the conclusion that 4 oz. gamma-BHC per acre should be applied twice, with an interval of 4 weeks.

Yield records covering 3 years for some plots and 2 for others show twofold and threefold increases following treatment. The claim for the efficiency of a 'Standard Treatment' is supported by records from large units of 50–200 acres so treated.

THE problem of capsids on mature cacao in Ghana, which produces the major part of the world's supply of cocoa beans, has been known for many years. Capsid damage was mentioned by Dudgeon [1] as long ago as 1910. Cotterell [2] described the nature of the injury and worked out the life-cycle of the capsid species. It is probable that the wide-scale cacao survey carried out to locate outbreaks of the disease 'swollen shoot' led to the realization of the extent of capsid injury and the degeneration of mature cacao which followed it. The (former) Gold Coast Department of Agriculture attempted to bring about a control of the capsid bug damage by treating cacao with the newer insecticides applied by modern machines.

Previous Investigations

Following the early papers by Cotterell, little further investigation was carried out until the establishment of an experimental station at Tafo in 1938, superseded by the West African Cocoa Research Institute (W.A.C.R.I.) in 1945. Various papers have been published from time to time by members of the staff of this Institute, notably Williams [3]. These papers deal principally with certain aspects of damage, mainly to mature cacao. Very little attempt was made to reduce damage to mature cacao except by certain cultural systems such as coppicing, i.e. cutting down trees to about 1 foot above ground.

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Nature of the Injury and Recent Observations on it

The early observations made by Cotterell [2] showed that certain species of capsid, notably *Sahlbergella singularis* Hagl. and to a lesser extent *Distantiella theobroma* (Dist.) of the family Miridae (formerly Capsidae) and possibly other species, caused injury to cacao by feeding on the new growth. The cacao tree grows in a series of 'flushes', usually two main flushes a year, eventually forming a continuous interlocking top-cover of foliage called a 'canopy' about 15 to 25 feet from the ground, an essential feature of cacao cultivation in Ghana. This canopy is very susceptible to injury by capsids which feed upon it intermittently. The capsid species mentioned, in common with other injurious capsids, possess saliva which is toxic to plant tissues, so that plant cells die out in areas surrounding a feeding puncture, manifested by a dark mark. Capsid feeding therefore leads to a dying-back of new growth, frequently followed by disease. In bad attacks the normal growth of the tree is retarded as new branches (chupons) become diseased and the tree begins to degenerate. A badly attacked stand of mature cacao presents a characteristic appearance in that leaves of the new growth fail on the attacked shoots and branches, and hang down, brown in colour, quite dead. Eventually the stand is reduced to mere 'poles' and, all vestiges of a canopy having been destroyed, the soil becomes exposed and excessive undergrowth develops.

It has been suggested [3] that capsid injury originates in a pocket started by mechanical damage to the tree. For example, forest trees maintained to provide shade sometimes fall, breaking down cacao trees beneath, which respond to injury by throwing out new growth. This is highly susceptible to capsid attack and so a focus of capsid injury is established. This sequence of events certainly occurs but is not necessarily the only way in which damage can start. Capsids occur naturally in the canopy of the cacao, where they feed among the fan-like branches. This can become thinned out as a result, with a loss of coverage, because of the lack of leaves on damaged branches.

Capsids also breed on cacao pods, which can be observed swarming with young capsid nymphs. They prefer to inhabit the part of the pod next to the tree trunk, where they feed, causing dark-brown sunken areas. This injury is unimportant in itself, but, with the removal of pods at harvest, the capsids tend to turn their attention to the new growth. The most severe capsid injury frequently occurs in November to February following on the pod-harvesting period.

Sahlbergella singularis is certainly the most common capsid species on cacao and can readily be found on all attacked trees. It probably causes most injury. It is a large robust capsid with markedly knobbed antennae. Much injury is undoubtedly caused by the adult capsids, which fly freely among the trees and which, when disturbed, quickly drop from the foliage. Considerable injury to shoots can also be caused by colonies of nymphs, especially as they approach maturity. Damage to pods, however, can follow feeding by other species, notably *Helopeltis bergrothi* Reut.,

a delicate capsid, orange in colour, and *Bryocoropsis* sp. These species evidently cause little or no damage to the tree itself.

Control of the capsids should lead to a rejuvenation of the tree and formation of the foliage canopy anew. At present it is estimated that loss of crop from capsids is equal to about one year's crop in five.

Organization of Present Trials

There is little doubt that the advent of portable engine-driven machines has made the application of insecticides to mature cacao a practicable possibility for the first time. The shoulder-mounted Kiekens–Dekker mist-blower was employed for application to this forest-grown crop, which is inaccessible to wheeled vehicles of all kinds.

Of the modern insecticides, it was known that DDT would prove suitable for killing capsids, and has in fact already been used as a 5 per cent. dust on mature cacao, and as an emulsion on young trees.

It was suggested that the best material was probably BHC (benzene hexachloride), as this had proved to be the most effective insecticide against capsids on other crops. The technique of mist-blowing enables small volumes of wash to be employed to cover the acreage, without the need for transporting large quantities of water. The ideal formulation of insecticides for mist-blowing is a miscible liquid. DDT and the gamma isomer of BHC (gamma-BHC) were both available as miscible liquids, DDT as a 25 per cent. product and gamma-BHC as a 20 per cent. product. The formation of an emulsion on mixing with water is instantaneous. Some insecticide dust was also included, based on crude BHC. Other engine-driven dusters were also available, e.g. the 'Mistral' (Birchmeier & Co. Ltd., Switzerland).

1954 Trials

In the summer of 1954 the Department of Agriculture started preliminary trials, selecting twenty-six trial sites of mature cacao showing obvious capsid damage and varying from 2 to 12 acres in extent. The general lack of uniformity in the condition of the cacao made the selection of sites difficult. A very simple layout was adopted. Only a single portion, approximately one-fifth of the area, was wired off and left untreated at each site to serve as a control plot. The areas were measured off, mapped, and cleared of undergrowth.

Treatment was begun in August 1954 and repeated monthly, the sites being allocated as shown in Table 1.

The total area involved was some 130 acres in the Eastern Region and Ashanti. The remaining five sites were used for local treatment of capsid 'pockets' or cacao pods only.

Assessments were organized consisting of a numerical estimate of the condition of the foliage of 50–100 marked trees as a sample, to be examined monthly in both treated and control areas. Records were also made of pod damage and harvest yields of pods.

The whole of the operation was carried out by two spray teams, one in the Eastern Region and one in Ashanti.

TABLE 1. *Treatments Applied at Various Cacao Sites*

Insecticide	*Amount per acre*	*Volume of spray per acre*		*Total no. of sites*
		5 gal.	*10 gal.*	
DDT . .	2½ lb.	2 sites	5 sites	7
	2 lb.	..	4 sites	4
gamma-BHC	8 oz.	1 site	4 sites	5
	6 oz.	..	3 sites	3
BHC dust .	10 lb.	..	..	2
Total .				21

Preliminary Results

In March 1955 all twenty-six sites were inspected for final appraisal. The results on the nineteen sites which had now received six monthly spray applications and the two which had received dust applications at 2-week intervals are summarized in Table 2.

TABLE 2. *Record of Capsids and Capsid Damage in Treated and Untreated Areas*

Treatments	*Number of sites*				*Total*
	Treated area		*Untreated area*		
	Damaged	*Capsids present*	*Damaged*	*Capsids present*	
DDT . .	10	4	11	7	11
Gamma-BHC	0	0	6	1	8
BHC dust .	0	0	0	0	2

The results were spectacular and showed conclusively that gamma-BHC gave excellent control of capsid populations and prevented capsid damage at all sites. There was lush and vigorous new growth in the treated areas, even on trees which had previously been reduced to mere trunks. Gamma-BHC was shown to be superior to DDT, with which damage was recorded on the treated area at ten out of the eleven sites. A curious feature of the experiments was that although all the untreated areas at the DDT sites showed damage—in some cases very heavy—there was little damage on the untreated areas at the gamma-BHC sites, which suggests a repellent action, or action spreading outside the treated area. This suggestion was borne out by observations on the two sites treated with 5 per cent. BHC dust[1] where damage was completely absent on both the treated and untreated areas. In this case, however, the phenomenon may be partly explained by the fact that dusts are likely to drift outside the treated area very readily. The five locally sprayed and pod-treatment sites gave inconclusive results.

[1] 'Agrocide' 3.

These observations confirmed the difficulties in working with small 'control' areas in this type of crop. The sites were obviously behaving as if the whole area had been treated. Only in some did the 'control' area act as a control. This type of extended effect was likely to invalidate records taken from 'control' areas and a new type of layout would have been desirable. It was, however, decided to continue with trials as laid out rather than sacrifice yield data so far collected.

Application

The Kiekens–Dekker shoulder-mounted mist-blower worked without difficulty, except for minor defects, during the 6-month period. Modifications were necessary, particularly in the adoption of a Warley Eclipse knapsack sprayer to retain the wash under pressure in order to force it to the top of an air tube which was extended by some 6 feet (see Fig. 1, Plate 11). This necessitated the employment of two men per machine. It was found that one machine could treat up to 10 acres per working day (8 hours). Ten gallons of wash per acre proved adequate and could be applied without difficulty, but with experience it was possible to reduce this quantity to 5 gallons.

Tree records

Marked trees were examined monthly in treated and untreated areas and points were awarded for the completeness of canopy, regeneration, and other features. Capsid injury to marked trees was also recorded by means of a points system. This system of recording proved unsuitable in practice as only at some sites did capsid injury occur on the marked trees. Likewise, fifty trees per site is really a very small sample from the total tree population. Some sites gave good records, e.g. Site No. 4, as follows:

TABLE 3. *Tree Record of Foliage Condition and Capsid Injury of Fifty Trees at Site No. 4, Eastern Region*

Treatment: DDT 2 lb. in 10 gal./acre

Date of examination	*Foliage condition*		*Capsid injury*	
	Treated	*Control*	*Treated*	*Control*
8 Aug.	173	283	144	130
3 Sept.	380	342	58	96
1 Oct.	392	314	51	115
29 Oct.	392	285	0	44
24 Nov.	450	347	0	53
23 Dec.	459	347	0	50
21 Jan.	425	316	0	108
17 Feb.	418	285	3	86

1955 Trials

Further sites were taken for additional experiments, principally to explore dosage of gamma-BHC and intervals between applications. The use of DDT was discontinued. Treatment at some sites began in April

1955 and at others in August 1955. Those sites previously treated were maintained and observations upon them continued, principally to secure yield data. In all, fifty-seven sites, including dusted sites and large-scale units, were inspected in February and March 1956. In the 1954 trials gamma-BHC in the form of a 20 per cent. miscible liquid ('Gammalin' 20) was used at rates of 6 oz. and 8 oz. active ingredient in 5 to 10 gallons of water per acre (Table 1). In the 1955 series many sites were to be treated with gamma-BHC at rates down to ½ oz. per acre, both 4-weekly and 8-weekly intervals being allowed (Tables 4 and 5). The amount of wash was fixed at 5 gallons per acre for all sites. Further trials were arranged with dusts, including the conception of 'strip' dusting and 'perimeter' dusting. The allocation of sites may be summarized as follows:

TABLE 4. *Sites Treated at 4-weekly Intervals*

Rate: gamma-BHC/acre	*Total number of sites*
6 oz.	6
4 oz.	6
2 oz.	7
1 oz.	6
½ oz.	1
	26

TABLE 5. *Sites Treated at 8-weekly Intervals*

Rate: gamma-BHC/acre	*Total number of sites*
4 oz.	6
2 oz.	8
1 oz.	6
	20

Results

The results were less clear-cut than previously, but the ability of gamma-BHC to control capsids was established beyond all doubt.

It was evident that the older sites (i.e. those treated in 1954) remained generally more free of damage than the new sites started in 1955 (Table 6).

TABLE 6. *Number of Sites Free from Capsid Injury after Treatment with Insecticide*

Type of site	*No. of sites*	
	Total	*Free of damage*
Old: started 1954 .	19	10
New: started 1955 .	27	6
	46	

This result is associated partly with the length of time the old sites had been subjected to treatment and partly with some low rates of gamma-BHC employed upon the new sites. Undoubtedly the higher rates and more frequent treatments gave the more reliable result.

Recommendations

In the light of the data recorded above, a recommendation for a Standard Treatment of mature cacao was formulated as follows:

Apply gamma-BHC at 4 oz. per acre[1] with a mist-blower twice at an interval of 4 weeks. Control should be maintained by regular inspection, and retreatment of localized areas carried out only when damage is observed.

Dusts

Insufficient information is available about dusts and dusting. As already reported, 5 per cent. BHC dust effected a complete control when applied at 10 lb. per acre at 2-weekly intervals. Later results were generally inconclusive, probably because the concentrations of gamma-BHC in the dusts in these later trials were too low; 10 lb. per acre of 5 per cent. BHC dust amounts to only 1 oz. gamma-BHC per acre. The possibility of control by 'strip' and 'perimeter' applications was not established.

1956 Trials

Still further sites were taken to explore the problem of retreatment after elimination of capsids by an initial treatment (called the Standard Treatment) with a mist-blower. This aspect of the investigations is not dealt with in this account. The experimental area had now increased to about 1,500 acres comprising over 100 individual units.

Yields

The most important records from the experimental units are cocoa yields. These have been recorded over the harvest period for 3 years. There are therefore three sets of records for the units begun in 1954, including the first year both for Eastern Region and Ashanti. In addition there are records for 2 years for units begun in 1955 (Tables 7, 8, and 9).

Upon these tables rests the vindication of the whole development of capsid control by spraying (or dusting) with gamma-BHC. Visually there is no doubt that treatment with gamma-BHC produces a remarkable change in the appearance of attacked cacao. Treated trees develop new foliage which remains upon the tree. Foliage upon untreated trees tends to wither and die off following shoot attack by capsids and by 'die-back'. Yield data are the most useful, permanent, and tangible record of the effect of treatments.

[1] 'Gammalin' 20 at 1 pint.

TABLE 7. *Yields of Cocoa (in lb. per acre) from Trial Sites—Eastern Region*

	Season 1954/5		*Season 1955/6*		*Season 1956/7*	
Unit no.	*Treated*	*Control*	*Treated*	*Control*	*Treated*	*Control*
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
1	49	10	259	391	557	117
2	124	179	339	190	841	391
3	144	247	519	782	616	830
4	94	42	247	96	507	257
5	240	183	718	366	565	460
6	154	185	277	281	374	280
7	277	..	390	..	685	..
8	254	256	526	536	680	873
9	127	26	511	213	476	177
10	137	294	361	657	610	1,133
	1,600	1,422	4,147	3,512	5,911	4,518

TABLE 8. *Yields of Cocoa (in lb. per acre) from Trial Sites—Ashanti*

	Season 1954/5		*Season 1955/6*		*Season 1956/7*	
Unit no.	*Treated*	*Control*	*Treated*	*Control*	*Treated*	*Control*
	lb.	*lb.*	*lb.*	*lb.*	*lb.*	*lb.*
1	134	168	280	207	651	480
4	358	253	636	450	928	522
5	250	311	480	499	654	562
7	451	146	569	219	978	413
8	719	246	819	238	1,082	351
9	224	..	505	..	563	..
10	176	166	295	381	495	534
11	228	148	415	230	550	285
12	559	566	840	608	1,520	1,543
	3,099	2,004	4,839	2,832	7,421	4,690

Yield of pods converted into lb. of dry cocoa per acre has increased in each year of the experiments on all treated units over 3 years both in the Eastern Region and Ashanti; in fact only two units out of the total of nineteen for which 3 years' records are available failed to increase in yield in each year of the experiment. These two units in fact fell by a few pounds in the third year. The best picture of the yield records is given by the total yields per unit for the three groups of units, i.e. Eastern Region units 1–10, Ashanti units 1–12 and 16–28. The total yields for all units have increased over the years. These increases in yield are in some instances quite remarkable, e.g. unit 2 (E.R.) which began at 124 lb. per acre in 1954, increased to 339 lb. in 1955 and yielded 841 lb. in 1956.

TABLE 9. *Yields of Cocoa (in lb. per acre) from Trial Sites—Ashanti*

	1955/6		1956/7	
Unit no.	*Treated*	*Control*	*Treated*	*Control*
	lb.	*lb.*	*lb.*	*lb.*
16	181	113	371	322
17	134	189	298	365
18	154	72	605	251
19	39	32	219	113
20	176	214	287	390
21	381	333	789	779
22	266	227	582	433
23	246	73	1,247	336
24	132	54	534	424
25	171	75	497	117
26	179	337	385	693
27	301	268	592	501
28	279	316	560	627
	2,639	2,303	6,966	5,351

A criticism of the trials has been made that the wired-off portion called the control (untreated) area gave similar yield increases, in some cases equally remarkable increases. This, according to some people, has invalidated the experiments. The explanation lies in the marked effect of the insecticide extending beyond the boundary of the treated area so that the control area was virtually treated as well. It would have been better to have recorded independent plots as control units. This in practice is difficult and certainly would have been so in the early days of the experiments before growers were satisfied that the experiments would not harm their cacao. There are, however, many yield records from untreated cacao; attention is drawn to the 1955 yields of units 16–28 in Ashanti which in fact can be taken as untreated controls for that year. The average yield from these 13 units before treatment was 202·9 lb. per acre. In 1955 units 1–12 after treatment yielded 537·7 lb. per acre in contrast to 344·3 lb. before treatment. A level of 528 lb. was reached in 1956 by units 16–28 after treatment.

In the first year of the trials all units receiving gamma-BHC were treated monthly—an overall high dose. Subsequently these units were used to explore different rates and different intervals as explained in Tables 4 and 5. Likewise, units 16–28 were also used in this way but, even so, increase in yield of both the treated and control areas were recorded a year later.

Tables 7, 8, and 9 give the individual yields for both treated and control areas and totals. Average yields taken from the units as grouped are given in Tables 10 and 11. At least twofold and sometimes threefold increases are evident.

Sites Nos. 2, 3, and 14 are omitted as being reorganized and unsuitable for comparison from one year to another. Sites Nos. 6 and 15 are pod sprays only and are omitted.

TABLE 10. *Average Yields for Treated Areas*

	Yields in lb. per acre		
	1954/5	*1955/6*	*1956/7*
Units 1–10 E.R. .	160·0	414·7	591·0
Units 1–12 A. .	344·3	537·7	823·3
Units 16–18 A. .	..	202·9	528·0

TABLE 11. *Average Yields for Control Areas*

	Yields in lb. per acre		
	1954/5	*1955/6*	*1956/7*
Units 1–10 E.R. .	158·0	372·2	502·0
Units 1–12 A. .	250·2	354·0	576·2
Units 16–18 A. .	..	176·6	411·5

Application

The speed of application has been increased by the introduction of a new mist-blower, the K.E.F. Motoblo, manufactured by Klein Motoren, Stuttgart, which has been modified to carry a polythene tank mounted on the machine itself for holding 2 gallons of wash. The Warley Eclipse knapsack previously used to retain the wash under pressure is no longer necessary and only one man is required to operate each machine. (See Figs. 2 and 3, Plate 11.)

The standard rate of treatment is now 5 gallons per acre. This can be applied with the Motoblo at the rate of 1½–2 acres per hour, making 12 acres per day per machine a possibility.

Cost

It is always difficult to arrive at exact costs of treatment, but the total cost of treating an acre of cocoa once with 4 oz. of gamma-BHC[1] is estimated to be about 12*s*.

Large-scale Units

The value of the recommendation called the Standard Treatment was tested on four large areas (see Table 12).

TABLE 12. *Large-scale Capsid Units*

Region	*Locality*	*Acreage*	*Perimeter*
Eastern Region	Akrozzo	120	10 yards
	Assamang Kese	225	..
Ashanti .	Subinso	52	10 yards
	Mamfo	102	..

These areas were all treated twice with gamma-BHC at 4 oz. per

[1] As 'Gammalin' 20.

FIG. 1. Application of insecticide using Kiekens–Dekker shoulder-mounted mist-blower with air extension tube and Warley Eclipse pneumatic sprayer

FIG. 2 (below). Application of gamma-BHC miscible liquid by Motoblo to mature cocoa

FIG. 3. Application of BHC dust by Motoblo dusting equipment

acre applied with a mist-blower at an interval of 1 month. Two units were maintained by a monthly perimeter treatment 10 yards deep around the entire area. The other two units received no such treatment.

One year later the number of trees recorded as damaged during the year was very small, see Table 13.

TABLE 13. *Number of Trees showing Capsid Damage during Year Following Treatment*

Location	*Acreage*	*Trees damaged*
Akrosso . .	120	12
Assamang Kese	225	268
Subinso . .	52	84
Mamfo . .	102	230

These units substantiate the general conclusion that capsids are quickly eliminated from an area by mist-blowing with gamma-BHC and reinfestation is slow.

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